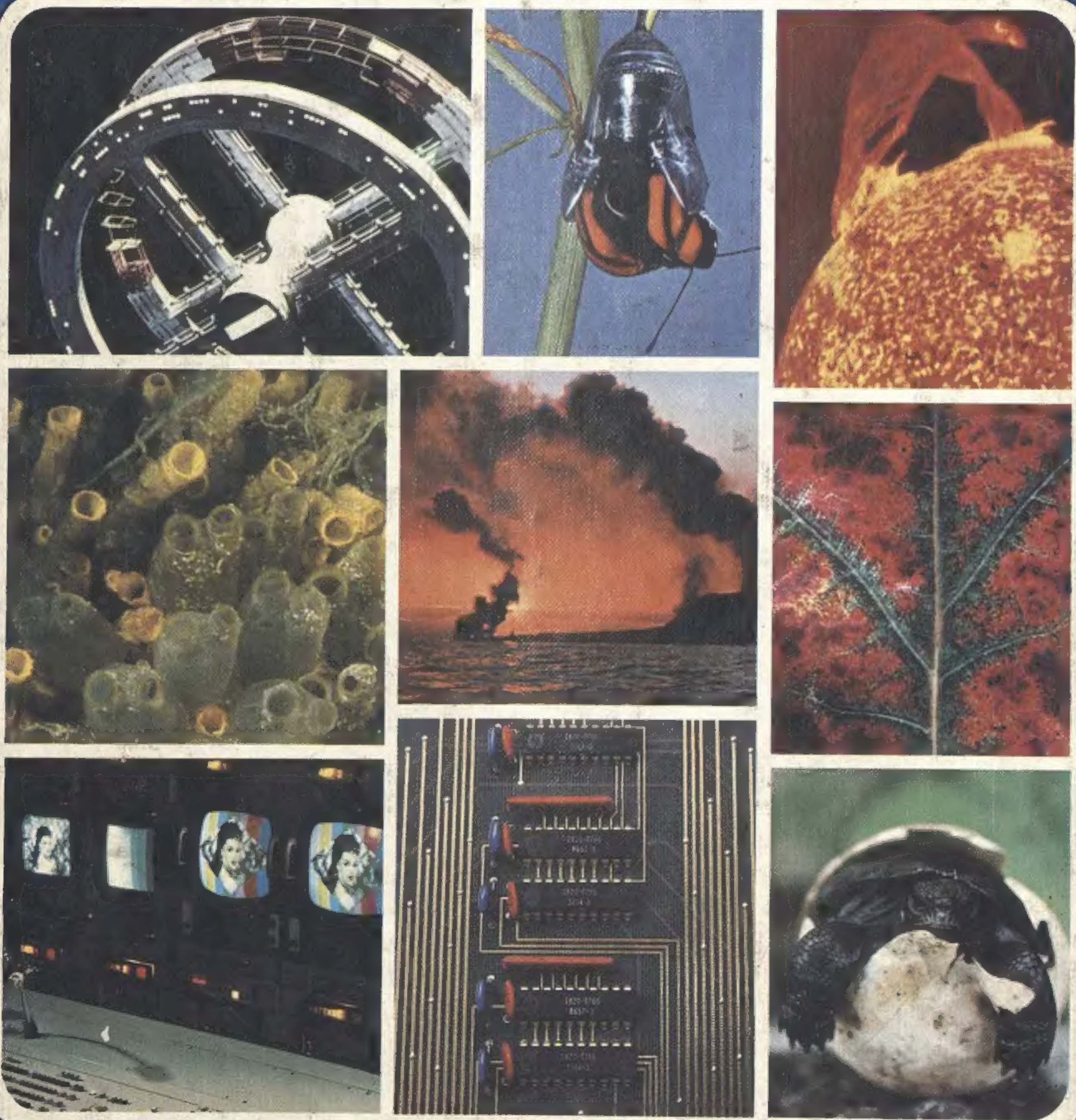
2

THE NEW BOOK OF POPULAR SCIENCE



THE NEW BOOK OF POPULAR SCIENCE

THE NEW BOOK OF POPULAR SCIENCE

VOLUME 2

Earth Sciences
Energy
Environmental Sciences

Library of Congress Cataloging in Publication Data

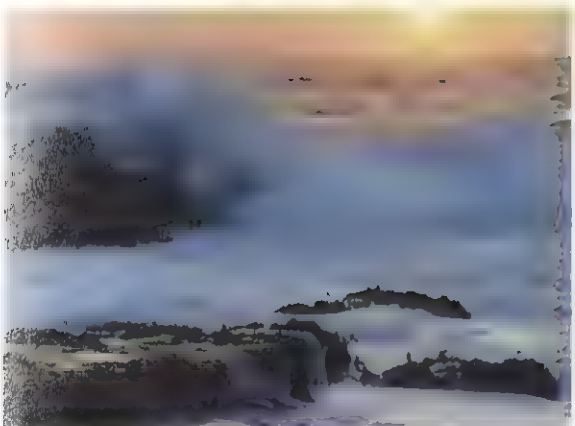
Main entry under title:
The New book of popular science.

Includes bibliographies and index.
Contents: v. 1. Astronomy & space science. Computers & mathematics.
1. Science—Popular works—Collected works.
2. Technology—Popular works—Collected works.
3. Natural history—Popular works—Collected works.
Q162.N437 1984 500 83-26595
ISBN 0-7172-1213-0 (set)

Volume 2

Contents

EARTH SCIENCES



[illegible] Wed'go Ferchland/B[illegible] Inc.
Above Dennis Brokow

The face of our planet is constantly being changed by the forces that create active volcanoes, such as Heimaey (left) in Iceland, and that produce waves that pound the coasts (above).

Ed Cooper

THE STUDY OF THE EARTH

To people before the seventeenth century, the earth was the center of all things—the hub around which revolved the sun, moon, stars, and planets. This geocentric, or "earth centered," theory has since been abandoned. We know now that the earth is a small planet and that it and its sister planets orbit a star called the sun. We know, too, that the sun is one of thousands of millions of stars in the "island universe" known as the Milky Way galaxy. This galaxy, in turn, is only one of thousands of millions of "island universes." Obviously, then, our planet is only an insignificant speck in the universe and not its center. Yet, tiny though it is, the earth is of supreme importance to us humans, for it is our home in space.

THE EARTH'S ORIGIN

How did the earth come into being? Since early antiquity, there have been many attempts, some very fanciful, to give a satisfactory answer to this question. Not, how-

ever, until the eighteenth century was there any hypothesis valid enough to be considered worth discussing by modern men of science.

In 1755, the great German philosopher Immanuel Kant suggested that the solar system—the sun, planets, moons, comets, and the rest—were formed from a nebula—a great mass of thin and veillike gas. Kant's theory did not cause much of a stir in the scientific world.

At about the same time, the French naturalist George-Louis Leclerc, Comte de Buffon, supplied his own answer to the question "How was the earth born?" He believed that, ages ago, the sun collided with a comet and that, as a result, a great deal of material was forced out of the sun. This material later cooled and gave rise to the planets. Buffon's choice of a comet as the colliding agent was unfortunate, since comets are utterly insignificant by comparison with the sun and could not possibly affect it. However, the collision theory he advanced was to serve as the prototype for a number of modern hypotheses based on the idea of collision of heavenly bodies.

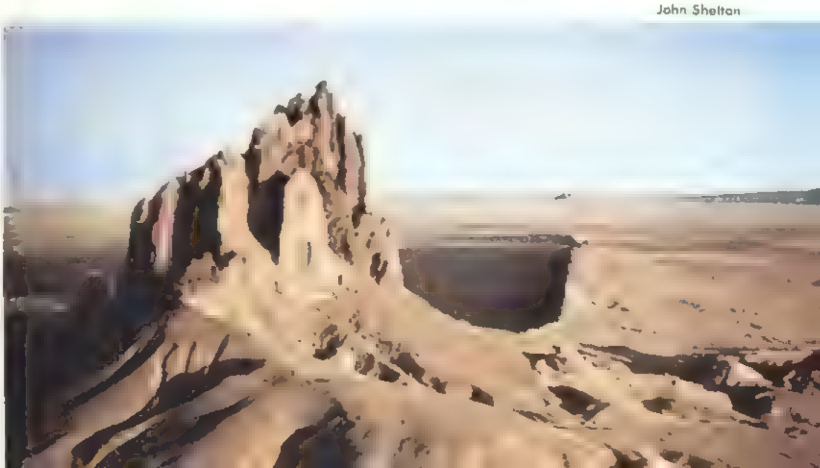
Nebular hypothesis. Pierre Simon, Marquis de Laplace, a French mathematical astronomer, rejected Buffon's theory and offered one of his own in 1796. It was called the nebular hypothesis, and it was widely accepted until the end of the nineteenth century. It suggests in various particulars the nebular hypothesis of Kant, but Laplace probably did not know of Kant's contribution.

According to Laplace, the members of the solar family once formed part of an enormous, slowly rotating mass of incandescent gases. This mass gradually cooled and shrank and became more and more spherical in shape. As it rotated with increasing rapidity, it developed a bulge around the equator. Finally, a ring of matter was flung off from this area. The ring cooled and contracted and ultimately became a planet, with its orbit in the plane that the ring formerly occupied. Another ring and still another one were thrown off from the central mass and each evolved into a planet. Eventually, all the planets were formed. The central mass became our sun. The planets themselves threw off rings into space, and these rings developed into planetary satellites, or moons.

Planetesimal hypothesis. About 1900, the astronomer Forest Ray Moulton and the geologist T. C. Chamberlin, both of the University of Chicago, presented a new theory, which they called the planetesimal hypothesis. A planetesimal is a small solid body revolving around a gaseous nucleus. According to Moulton and Chamberlin, a star speeding through space came very close to our sun. The greatly increased gravitational forces between the two stars caused each to raise great tides in the hot, gaseous body of the other.

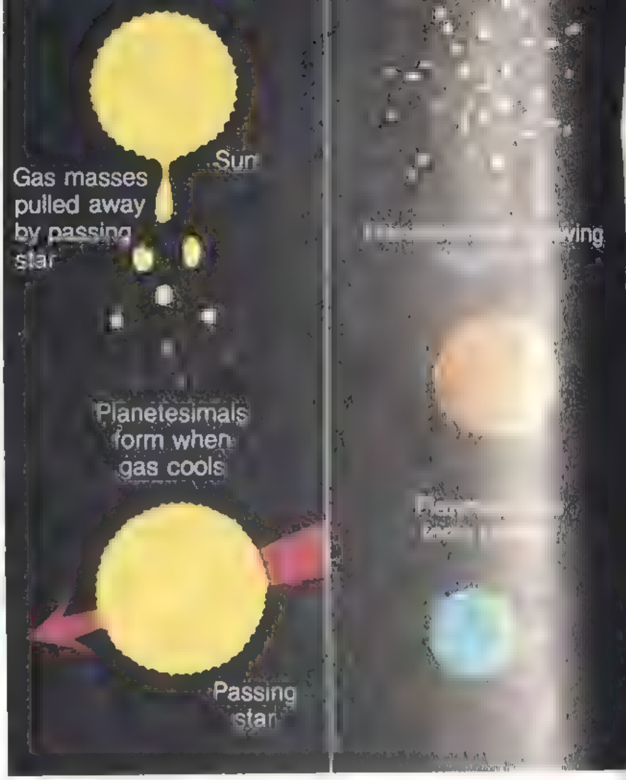
As the solar tides caused by the pull of the passing star became greater and greater, masses of gas were thrown clear of the sun and began whirling round and round. Some of them followed the other star as it dashed off into space. Others, held by the attraction of the sun, started to move around that body. The great solar tides subsided when the other star moved on. The masses of gas flung off from the sun settled down into orderly paths around it. As they became

John Shelton



Ship Rock Peak, New Mexico, is the igneous-rock remains of an ancient volcano.

Nebular Hypothesis



Planetesimal Hypothesis

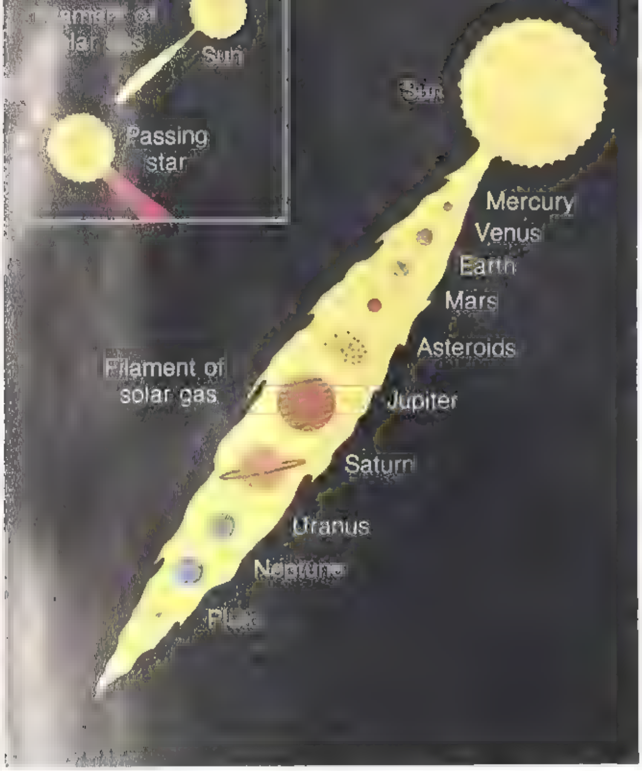
cooler, they changed into liquid form and then gradually became small solid masses. These fragments—planetesimals—eventually drew together to form planets.

Tidal theory. In 1918, Sirs James Jeans and Harold Jeffreys, British scientists, worked out the so-called tidal theory. It was also based on the idea of collision. These scientists differed from Moulton and Chamberlin in that they did not believe that the planets were derived from great numbers of small bodies, or planetesimals. Their idea was that the planets were formed directly from the original mass of gas pulled out of the sun by a passing star, and not by the building up of large solid bodies from small particles. According to the tidal theory, as the star approached, or even sideswiped, our sun, its gravitational pull drew out a long cigar-shaped filament of gas from the sun—a filament largest in the middle section and tapering at both ends (see diagram).

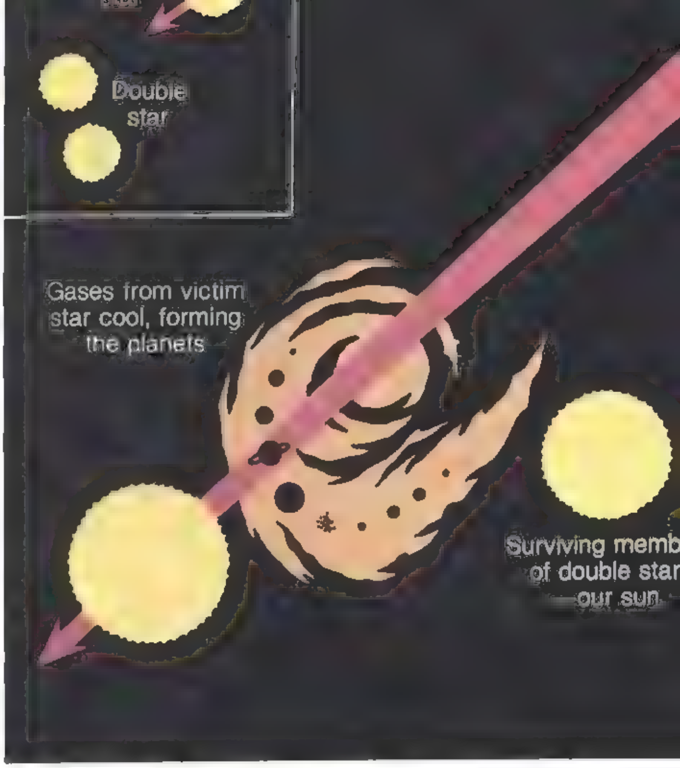
Lyttleton theory. The astronomer R. A. Lyttleton offered still another modification of the collision theory. He suggested that the sun was originally a double star, with the two stars moving around a common center of gravity. A passing star may have moved close to one of the two suns and may have disrupted it, transforming it into a vast expanse of swirling gases. The surviving star would be our sun. The victim of the collision would in time have evolved into our planets. In some ways, the Lyttleton hypothesis gives a better explanation of the origin of the solar system than do the other versions of the collision theory.

Many modern astronomers are inclined to discount theories based on the collision or near-collision between the sun and a passing star. They believe that the universe as a whole has evolved in a gradual and orderly fashion, and not through chance catastrophes beyond the normal course of events.

Modifications of the nebular hypothesis. The German astronomer C. von Weizsaecker presented a nebular hypothesis of his own in the 1940s. He held that a veil of gaseous matter once extended outward for vast distances from around the equator of the primeval sun. Most of this veil was composed of the light elements hydrogen and helium. Eventually, the pressure of solar radiation and heat drove off much of



Tidal Theory



Lyttleton Theory

the hydrogen and helium, leaving the heavier elements behind. The latter gradually collected in a series of concentric, kidney-shaped masses. These masses, attracting other substances in space, evolved into the planets.

Another nebular hypothesis was proposed by the Dutch-American astronomer Gerard P. Kuiper. He assumed there was originally a disk-shaped nebula of tremendous extent, with the protosun, or the sun-to-be, at the center. The over-all composition of the nebula was uniform. The temperature was low because the protosun had not yet begun to radiate. This cold nebula began to break up and to concentrate into separate masses—the protoplanets, or planets-to-be. The matter at the center—the protosun—also concentrated under the force of gravitation. As it contracted, it became hotter and hotter. Radiant heat from the protosun drove most of the lighter elements (particularly hydrogen and helium) out of the protoplanets and the nebula itself. In each protoplanet, most of the heavier elements (iron, nickel, and several other metals) would concentrate toward the center.

Dust-cloud theory. A dust-cloud theory of the universe was proposed by the U.S. astronomer Fred L. Whipple. According to Whipple, the solar-system-to-be was at first a vast cloud of cosmic dust and gases, which assumed a disklike shape. Irregularities within the cloud brought about rotation. The rotating dust and gases became concentrated and the cloud collapsed. The solid particles within it collided, stuck together, and became the planets. The gases at the center of the former cloud developed into the sun.

These are only a few of the many theories that have been proposed to account for the birth of the earth. Not one of them can be regarded as wholly satisfactory and not one is universally or even widely accepted at the present time.

THE EARTH'S STRUCTURE

We are on more solid ground when we analyze the structure and composition of our planet, for scientists have been able to accumulate an imposing mass of evidence. We have particularly exact information about the relatively thin outer shell of the earth—the so-called crust—because we

have been able to examine some part of it, at least, at first hand.

THE CRUST

The earth's crust is made up of rocks, which consist of various minerals. There are many different kinds of rocks, but they may be divided into three basic types: igneous, sedimentary, and metamorphic.

The *igneous* rocks (literally, "rocks produced by fire") were once intensely hot molten substances that solidified either at the earth's surface as in the case of basalt or deep within it as in the case of granite. We shall have more to say about the igneous rocks later in this article. They were the original rocks of the earth's crust.

Sedimentary rocks are derived from rock fragments, moved and spread by wind, water, and other agencies. Laid down on land or the sea floor, they have gradually been pressed together and cemented. Sedimentary rock forms layers varying in thickness from a few centimeters to thousands of meters. These layers make up most of the surface of the earth's crust. Among the most important sedimentary rocks are sandstone, limestone, and shale.

Certain layers found in sedimentary rocks have been derived from the remains of plants that once flourished in swampy areas. These remains were buried under later sediments and were subjected to great heat and pressure. At last they were converted into coal. Animals have helped build up various kinds of sedimentary rocks.

The rocks of the third main division—the *metamorphic rocks*—are made up of igneous or sedimentary rocks that have been transformed in the course of the ages. Various factors enter into metamorphism, or the formation of metamorphic rock: pressure, heat, the presence of water, chemical changes. The particles of the original rock are forced into new arrangements. New minerals may be formed. Sometimes the metamorphic rock retains traces of the rock formation from which it was derived. Sometimes it is an entirely new rock to all intents and purposes. Among the metamorphic rocks are marble, slate, and the granite gneisses. Marble is derived from limestone; slate, from shale; the granite gneisses, from various granites.

The top layer of the crust, in land areas, is generally covered with soil. Made up in large part of weathered rock particles, soil also contains a considerable proportion of organic matter, derived from the decaying products of formerly living things. The soil supports the plant life of the earth and its animal life as well, since the food of animals is derived, either directly or indirectly, from plants.

INTERIOR OF THE EARTH

The crust of the earth extends downward for only a few kilometers, comparatively speaking—about 30 to 40 kilometers on the average, in continental areas and only about 5 to 10 kilometers below the main ocean floors. Below the crust lies the more or less mysterious interior of the earth. Since we have thus far not been able to obtain first-hand information of this region, we must rely on indirect evidence in studying it. We must analyze, for example, the records we obtain of earthquake waves that pass through the earth's interior and that are affected in different ways by the various layers through which they move.

The interior of the earth consists of two main regions—a nickel-iron central core, with a diameter of about 7,000 kilometers and a surrounding mantle, about 3,000 kilometers thick. Scientists have calculated the density of the earth's interior at various levels, its temperature, and its elasticity. They have made an analysis of the composition of the materials contained in these regions. They have also theorized about the generation of the magnetic field of the earth far below the crust.

THREE SPHERES OF THE EARTH

We have discussed thus far the basic rock structure of the earth. Actually, the rocks (and the soil, which is largely derived from the rocks) form only one of the three provinces, or "spheres," into which the earth is divided. Rocks and soil are the solid part of the earth—the lithosphere ("sphere of rock"). The earth's waters, found in oceans, seas, inland lakes,

streams, ground water, and continental ice formations, constitute the hydrosphere ("sphere of water"). Finally, the invisible ocean of air that surrounds the earth makes up the atmosphere ("sphere of air").

Sometimes these main divisions overlap. Thus the atmosphere contains water, in the form of vapor, as well as the rock particles called dust. A good deal of air is absorbed in the hydrosphere, and a vast quantity of rock particles are held in suspension in its waters. The lithosphere contains both water and air.

CHANGING LAND FEATURES

We who dwell upon the earth are particularly familiar with the landscape features of the surface—plains, mountains, oceans, streams, waterfalls, canyons, natural bridges, and the like. These features are anything but stable: they are constantly being modified by certain natural processes that have been at work upon them since the early days of earth history.

The process of *degradation* represents the wearing down of the earth's rocks as they are acted on by water, air, and ice. When water falls on the land as rain or snow, much of it makes its way to mountain streams, then to larger rivers, and finally to lakes or oceans. As the water flows, it gouges out rock particles from the bottom and sides of stream beds. These particles then serve as abrasives to scour out still more rock fragments. The waves of the ocean wear away the rocks of the coast as they pound against them. Water may penetrate rock formations through cracks. When it freezes it expands and gradually causes the breakdown of the outer layers of the rock mass. The winds carry off loose rock particles, raising the lighter ones into the air as dust and rolling the heavier particles along the ground. Glaciers, which are rivers of ice, transport masses of rock fragments and exert a grinding action on the surface of the rocks along which they pass.

Rock particles transported by water, glaciers, or wind are ultimately deposited and build up new areas of the earth's surface. This building-up process is called *aggradation*. The fragments carried by streams or gouged out of coast rocks by the beating of the waves ultimately drop to the bottom of rivers, lakes, or seas and form mud or sand. Rock particles borne by glaciers are laid down as deposits when the ice melts. Fragments transported by the winds finally come to rest as sand dunes or as dust layers on the earth's surface. In the course of time, wind-borne rock particles may come to form thick layers.

Certain vast changes in the earth's surface have been brought about by *diastrophism:* that is, by movements of solid parts of the crust with respect to one another. The crust of the earth may be warped, folded, raised, or lowered. Some diastrophic movements are very slow and gradual. Others, such as the familiar earthquakes, which may suddenly lower or raise large masses of land or shift their positions relative to one another along fault lines, are rapid and violent.

Everywhere, there are evidences of diastrophism. We see the workings of this process, for example, when we examine the sides of cliffs where successive strata have been bared. In one place, the strata are moderately tilted. In another, they are folded, forming a series of undulating crests and

The *Alvin* of the Woods Hole Oceanographic Institution, in Massachusetts, is a small exploratory submarine, which can descend to great depths. This small vessel requires a mother ship, *Big Lulu*, to move it from ocean to ocean.

Jack Donnelly/WHO

NASA

Laser Geodynamic Satellite (Lageos) is studying the earth's rotation and infinitesimal crustal movements. It contains hundreds of retrocubes on its surface

troughs. Sometimes, a fracture has taken place in a stratum, and often the sides of the fracture have moved with respect to one another.

In certain places, the land has risen noticeably in the course of the ages. We know that sedimentary rocks containing marine fossils must have been under water at one time. Such layers may now frequently be found high above sea level—in the Himalayas, in the Rockies, and in the plateau country though which the Grand Canyon of the Colorado has been carved out. Elsewhere, the land has been just as noticeably depressed. In the delta of the Ganges River in India, for example, bones of land animals have been found a hundred meters below the level of the sea.

Finally, there is the process of *volcanism*, also known as *vulcanism*. It is the movement of molten rock matter, called *magma*, and its transformation into rock formations. The heat that causes rocks to become molten within the earth was once thought to be a residue from the early period of the earth's history, when the entire planet was in a molten condition. Modern geologists, however, are inclined to be[illegible] that the earth's internal heat is due [illegible] large extent at least, to radioactive [illegible] In the process of natural radioactivi[illegible] tain elements, such as uranium an[illegible] rium, spontaneously disintegrate in[illegible] elements, yielding great quantities o[illegible] energy as they do so. It is known tha[illegible] um and thorium are to be found, ge[illegible] in very small amounts, in all rocks. G[illegible] gists speculate that the heat released b[illegible] integrating uranium and thorium [illegible] would accumulate in separate local [illegible] since rocks are poor conductors of he[illegible] time, this heat would be great eno[illegible] melt the surrounding rocks and to prod[illegible] magma.

Some magma movements are confi[illegible] within the earth, and the resulting ign[illegible] rock also remains buried there unless [illegible] bared by quarrying activities or by th[illegible] fects of erosion on the earth's surface [illegible] some instances, the magma, moving [illegible] cracks in the rock, reaches the earth's [illegible] face and flows out over it. Or else it ma[illegible] ejected, together with great volume[illegible] steam and other gases, from the vent[illegible] volcanoes. The magma that moves ove[illegible] surface of the earth is called *lava*. It co[illegible] hardens, and becomes igneous rock. Wh[illegible] ever rock formations resulting from th[illegible] process of volcanism are bared at the su[illegible] face of the earth, they are subjected to th[illegible] process of degradation.

EARTH SCIENCES

Such then, in brief, is the ever-changing planet upon which we dwell. The study of this planet is particularly the province of what we call the earth sciences. The basic earth science is *geology* (from the Greek *ge:* "earth" and *logos:* "science"). It examines the different processes by which the rock structures and the landscape of the earth have come into being and the present composition of the earth—its exterior and interior. Geology also reconstructs the sequence of past changes in the earth's structure. This leads to an understanding not only of the history of the earth itself, but also of the different forms of life that dwelt upon it in past ages.

Geology has a number of subdivisions. The science of *petrology* studies the character and origin of all kinds of rocks. *Structural geology* examines the structural arrangements of rocks, brought about as a result of folding and fracturing. The minerals that make up rocks are studied in the science of *mineralogy*. *Stratigraphy* deals with the sequence of rock layers, particularly sedimentary rock. *Geomorphology* considers the various land forms that have been sculptured by such surface agencies as wind, flowing water, and precipitation. *Glaciology* deals with the processes connected with ice and snow. *Paleontology* studies the plant and animal fossils buried in the earth and the evidences of the gradual development of life in past ages. The rock deposits that are valuable to man (metals, coal, petroleum, and the like) are the subject matter of *economic geology*. Exploration for valuable deposits and their removal is called *mining geology*. Civil engineers must know about the qualities and strength of the earth and rocks they encounter and also use in their constructions; this study is *engineering geology*.

Certain other sciences may be included under geology by some experts. *Geophysics* deals with the physics of our planet. *Geochemistry* treats of the composition of the earth's rocks, minerals, soils, air, and water. The soil itself belongs under the science of *pedology*. *Hydrology* takes in all the bodies of water—lakes, streams, and swamps—on the landmasses of the world. *Marine*, or *submarine, geology (geological oceanography)* is concerned with the sea bottom and shorelines. The exact delineation of the earth's features is the concern of *topography*, *hydrography* (for water bodies), and *mapmaking*.

Fields closely related to geology are: *physiography (physical geography)*, dealing with landscapes in different countries; *ecology* and *biogeography*, concerned with life in relation to its environment and to the land and sea; *limnology*, with the suitability of water for life in it; *oceanography*, the science of the sea; *meteorology*, the study of weather; *climatology*, the study of climates; and *astrogeology (planetary astronomy)*, dealing with the nature of planets, moons, asteroids, and meteorites.

NASA physicists check the precision of the 426 reflectors of the Laser Geodynamic Satellite. This satellite can measure the relative positions of participating ground stations to within three centimeters. With such precision, they can measure crustal movements, which will help in earthquake prediction.

NASA

Dick Dietrich Alpha

Devil's Tower National Monument in Wyoming is an exposed volcanic neck.

THE EARTH'S CRUST

by Terence T. Quirke

When we see rocky ridges and sheer cliffs breaking harshly into a pleasing pattern of green forest and undulating fields, we are apt to think of the rock formations as intruders. Yet such formations make up the real crust of the earth, in land areas and sea areas alike. The soil of the land, upon which plant life and animal life flourish, has been derived from rock. It is an exceedingly thin film, composed chiefly of bedrock that has been broken into fragments by weathering and erosion. In the ocean areas, deposits of mineral matter and of plant and animal remains also form a superficial covering upon the underlying bedrock of the sea bottom.

The earth's crust is relatively thin—about 30 to 40 kilometers deep under the continents and less than 10 kilometers deep under the ocean floor. An interesting feature of the ocean crust is its age. It is younger than the crust under the land areas. Many geologists think that new material is constantly being added to the oceanic crust. This material, they believe, comes from the earth's interior and emerges along an oceanic seam, or ridge. The sea floor then spreads, pushing the older crust material farther away from the ridge.

The rocky crust of the earth is made up of three kinds of rock formations: igneous, sedimentary, and metamorphic rocks. The igneous rocks have been formed by the solidifying of molten, rock-producing matter. The sedimentary rocks consist of sediments, or fragments, that have been transformed into rocks in the course of the centuries. The metamorphic rocks were originally igneous or sedimentary rocks, transformed by changes in temperature and pressure and other factors operating within the crust of the earth.

IGNEOUS ROCKS

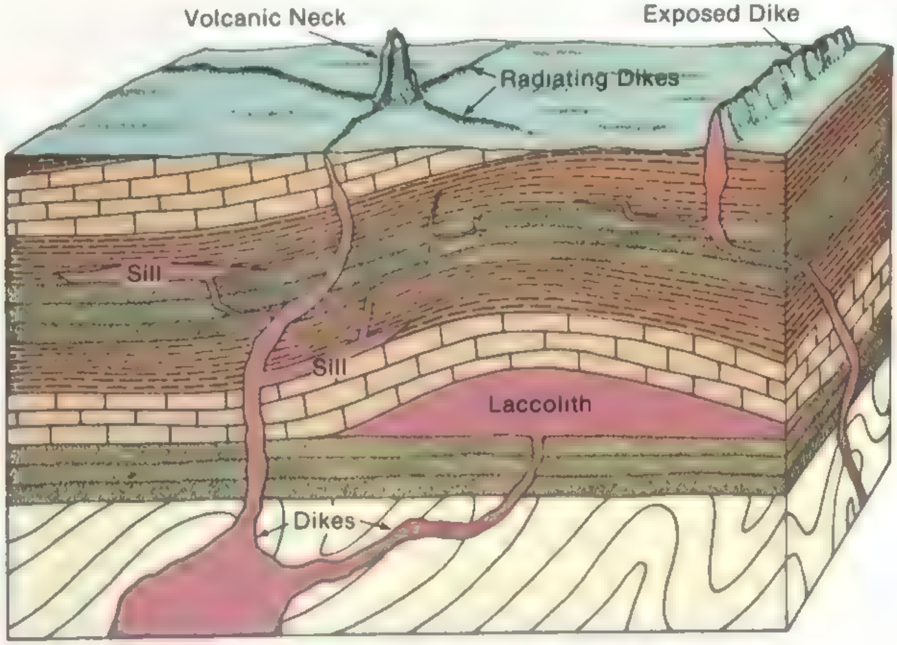
The molten, seething mass from which the igneous rocks have been formed is called *magma*. It contains various gases in solution, but for the most part it is made up of rock-forming minerals, dissolved in haphazard fashion.

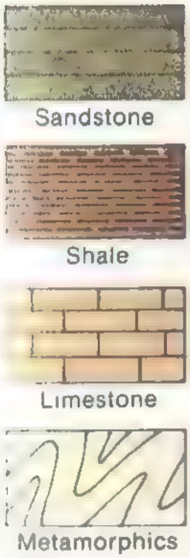
According to some theories of the earth's formation, our planet was once a mass of swirling gases cast off from the sun. As these gases gradually cooled, they were

converted into liquid form. This liquid—the magma—began to cool and the minerals it contained began to crystallize. Heavy minerals tended to sink in the still-liquid mass of the magma. Lighter minerals floated on top of the heavier ones. As the cooling continued, the rocks began to solidify. In time they formed a solid crust.

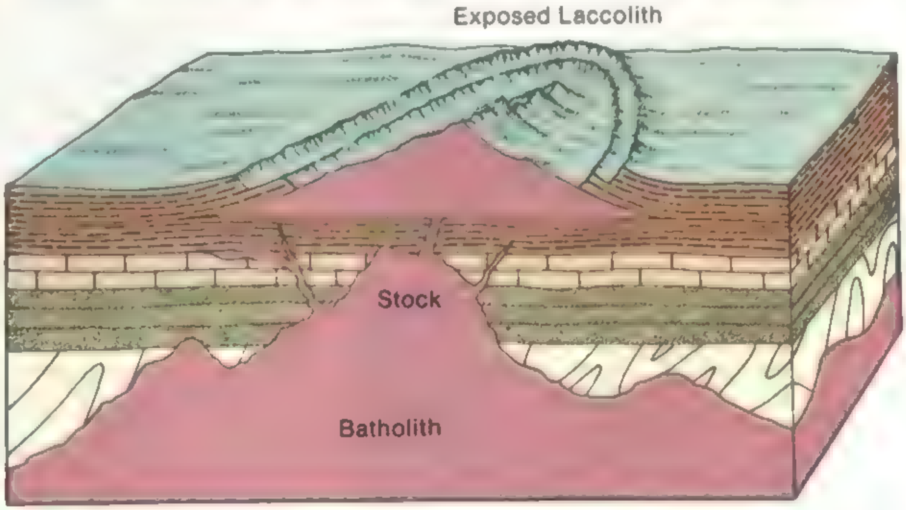
This represented only one stage in the formation of igneous rock. Vast quantities of magma at extremely high temperatures were imprisoned under the crust. The gases contained in the magma exerted enormous pressures not only upon the igneous rocks that had already been formed but also upon an entirely different kind of formation—the sedimentary rocks.

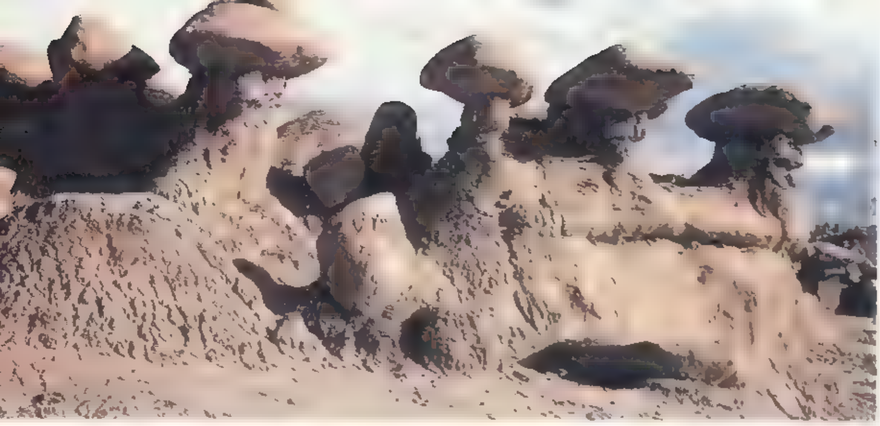
The original igneous rocks of the





In the top diagram we see various types of intrusive masses. Molten rock moving across rock layers forms dikes. When it pushes between the layers, it produces sills; if the overlying rock is arched upward, the result is a laccolith. The lower diagram shows a stock and a batholith. They result when intrusive masses extend downward. The rock layers in these two diagrams are identified at left.





What appear to be g[...] mushrooms are act[...] eroded sandstone, a c[...] mon sedimentary [...] Sandstone is sand th[...] has become cement[...] into stone.

Richard Weymouth Brooks/PR

earth's crust and the sedimentary rocks that were formed later were sometimes unable to resist the pressure of the magma under the crust. The liquid rock would then make its way up to higher levels.

In some cases the advance of the magma was stopped by the rock layers in its path—only its gases escaped. The magma gradually cooled and solidified under the rock layers that made up the upper part of the earth's crust. Igneous rocks that have been formed in this way are called intrusive masses.

In other cases the magma failed to be checked in its upward progress by the surrounding rocks. It reached the surface of the earth and was discharged either through a simple opening, or volcanic vent, or through a crack in the rocks. Igneous rocks formed from magma extruded, or thru[...] out, from the earth are known as extrusiv[...] masses.

Granite is a common igneous rock.

Dr. Kurt E. Lowe

INTRUSIVE MASSES

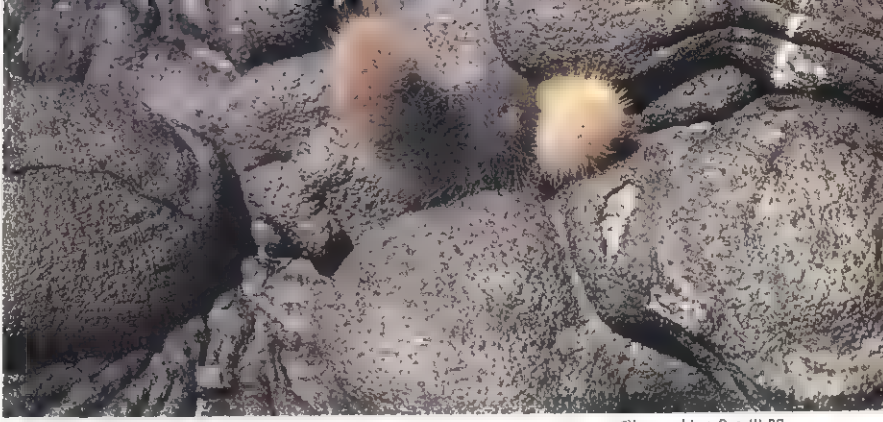
Intrusive masses of igneous rock form a considerable portion of the earth's cru[...] On the basis of their shape and their rel[...]tion to the rocks that surround them, the[...] may be divided into several classes—dike[...] sills, laccoliths, volcanic necks, batholiths and stocks.

Dikes have been formed by magma that has cut its way across rock layers and that has been solidified in the fissures produced in this way. In certain instances dikes are exposed to view. This is either because the original fissures extended to the surface or because the rocks that once covered them have been eroded away in the course of the ages. In certain area, dikes are very numerous and close together. They may be parallel to one another or may radiate from a common center, like the spokes of a wheel.

The mass of igneous rock called a *sill* is formed in much the same way as a dike, except that the magma of a sill thrusts itself into the spaces between the layers of the surrounding rock. It is parallel to these layers. The magma has displaced the two adjacent beds between which it has been inserted. Its thickness measures the extent to which the surrounding rock has been shifted. The resulting sill may be many hundreds of meters thick.

A sill may be horizontal or it may lie tilted along with the rock layers to which it is parallel. In the latter case, it may mean that the sill was intruded either into already

Cacti grow in a crevice of a lava flow. Lava is an igneous rock.



©Leonard Lee Rue III/PR

tilted, or dipping, rocks or into flat-lying beds that, with the sill, were later shifted by forces in the earth's crust. In the United States, the bluffs known as the Palisades, along the shore of the Hudson River in New Jersey, are the edge of an igneous sill many meters thick, tipped downward to the west some time after its formation.

Sometimes, during the formation of a sill, the magma does not spread easily enough and causes the overlying layer of host rock to arch upward. The resulting igneous mass, having the shape of a lens in cross section, is called a *laccolith* (Greek for "reservoir of stone"). It has a flat floor, connected by a "stem" to the magma source below, so that as a whole it resembles a toadstool in side view.

The vent of a dead volcano may be filled with a cylindrical mass of solid lava known as a *volcanic plug*, or *neck*, which may be more than a kilometer thick. It may connect with a large underground mass of igneous rock called a *stock*, which may have supplied lava to the erupting volcano in the magmatic stage. Dikes and sills often emanate from the plug. If the surrounding rocks have been eroded away, the plug stands out as a neck, or tower.

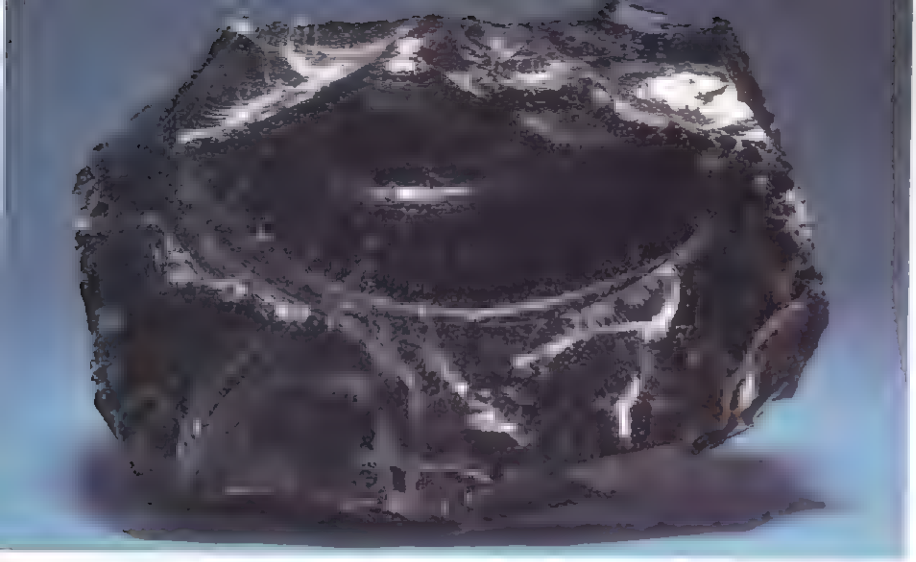
Huge intrusive masses of igneous rock enlarging and extending downward to unknown depths are called *batholiths* ("deep rocks," in Greek). They differ from laccoliths in that they do not show signs of a definite floor, as do the laccoliths. Besides, the magma from which they were derived made its way through rock layers and not between them. Of course, as in the case of other intrusive masses, the batholiths are exposed to view only when the overlying rocks are eroded away. One of the world's largest batholiths forms the Sierra Nevada range, in California. It has been uncovered over wide areas by erosion. Batholiths form the cores of many mountain ranges.

EXTRUSIVE MASSES

There are several kinds of extrusive masses. In some cases, magma has been extruded from the depths of the earth with explosive force through a volcanic vent. It has formed a spray of atomized rock stuff shooting high into the air. The fragments have later been converted into rock. In other cases, the magma has not been blown from a volcanic vent, but has welled up from it and has poured out, as lava, over the countryside. It has been transformed into igneous rock upon cooling.

MINERALS IN IGNEOUS ROCK

The minerals that have contributed to the formation of igneous rocks are rather limited in number and in variety. Commonest of all is quartz, a very hard mineral which is a compound of silicon and oxygen. The feldspars are also abundant. These are light to dark in color and contain potassium, sodium, or calcium, as well as aluminum, silicon, and oxygen. Pyroxene and hornblende, containing different metals plus silicon and oxygen, are darker and heavier. The micas are sheetlike minerals composed of aluminum, other metals, oxygen, and silicon. Magnetite, an iron-oxygen compound, is heavy and magnetic. Olivine, consisting of iron, magnesium, oxygen, and silicon, is a green mineral.



Joel E. Arem

Obsidian, a shiny black rock, is l cooled quickly. It crystals. It was American Indians t arrowheads

DIFFERENT TEXTURES

Igneous rocks differ from one another in texture: that is, in the size, shape, and arrangement of the particles of which they consist. The size of the individual grains depends upon the rate at which the magma cooled. If the process was slow, the mineral crystals had a longer time to form and so they grew comparatively large. The result is a coarse-grained rock. If, however, the magma cooled quite rapidly, the crystals did not have much time to grow. The resulting rock formation is fine-grained. Generally there is a relationship between the depth at which the rock was formed and the coarseness of its grain: the greater the depth, the coarser the grain.

VARIETIES OF IGNEOUS ROCKS

There are many varieties of igneous rocks. Several hundred are recognized in some classifications. However, the crust of the earth is made up principally of only a few kinds. One of the most common is the plutonic, or deep-seated, rock called granite, which occurs in the form of huge, irregular masses. Granite consists chiefly of quartz and feldspar. It also contains some hornblende and mica (the black variety called biotite). This type of rock generally has a comparatively even texture. The variety of granite called pegmatite is often found in dikes. It is very coarsely granular. Pegmatite is the source of much of the white mica used in commerce.

Like granite, diorite is an even tured rock. However, unlike granite, it tains no quartz. It is made up of feld and of one or more dark minerals, cl hornblende, pyroxene, and biotite. In rock called gabbro, these dark min predominate. Feldspar is also present.

The basalts are the commonest o the extrusive igneous rocks. They black, brown, dark gray, or dark gree color. The basalt formation in the Colun Plateau, in the northwestern part of United States, covers an area of o 500,000 square kilometers and ranges more than 1,200 meters in thickness. The are also vast basalt formations in western India and in the northern British Isles.

Rhyolite is like granite in composition An extrusive rock with a very fine, or felsitic, grain, it may have a porphyritic texture if there are large crystals of feldspar, quartz, or mica in it. (Porphyritic rocks contain a mixture of coarse and fine grains.) Andesite is the extrusive form of diorite. Darker than rhyolite, it too may be porphyritic. Its name comes from the Andes Mountains in South America, where it is abundant.

Among the most striking of the glassy rocks found among the extrusive masses are obsidian and pitchstone. Obsidian is a lustrous rock, black, gray, yellow, or brown in color. It is found in many different parts of the world. One of the largest formations is Obsidian Cliff, in Yellowstone National

Coral, a sedimentary rock formed from the skeletons of coral polyps, is widely used to make beautiful ornaments.

EPA

Park in the western United States. Pitchstone is much less lustrous than obsidian.

SEDIMENTARY ROCKS

Some sedimentary rocks have been formed from igneous rock. The surface layers of igneous rock have been constantly acted upon by erosive forces, such as changes in temperature, running water, and the blasting effects of fragments hurled by the wind. As a result, some of the igneous rock at the surface has been broken down into fragments. These fragments, swept along by winds, glaciers, streams, and shore currents, have been deposited in lakes or in shallow parts of the sea. They have been pressed together under the weight of later accumulations and have been gradually transformed into sedimentary rock. Sedimentary rock has also been formed from plant and animal remains and through the evaporation of seawater.

The sedimentary layers of the earth's crust make up most of its surface area. Each layer ranges in thickness from a few centimeters to several meters. In some places, there are only a few layers. In others, there are vast accumulations of beds, several kilometers thick.

Generally speaking, the older the bed, the more thoroughly the sedimentary rocks have been cemented. The fragments of young rocks are so loosely held together that they may sometimes be quarried by digging with a spade. The older rocks, however, are generally so solid that they cannot be quarried unless they are drilled, blasted with dynamite, and broken into still smaller fragments with pick or sledgehammer.

FRAGMENTAL, OR CLASTIC, ROCKS

The sedimentary rocks that are made up entirely of particles of other rocks are known as fragmental, or clastic, rocks. ("Clastic" comes from the Greek *klastos*, meaning "broken.") The fragments from which the fragmental rocks are derived are generally classified, on the basis of size, in four groups: gravel, sand, silt, and mud.

Gravel is the coarsest sediment of all. It consists of fragments that are at least two millimeters in diameter. Gravel fragments range from small pebbles to big boulders. In between there are the particles called cobbles. Sand sediments consist of rounded grains ranging from 2 millimeters in diameter to $1/16$ millimeter. Particles smaller than $1/16$ millimeter and at least $1/256$ millimeter in diameter are called silt. The finest sediments—muds and clays—consist of fragments under $1/256$ millimeter in diameter.

When more or less rounded gravel particles—pebbles, cobbles, and boulders—are cemented together, they form the type of rock called *conglomerate*. In the variety known as *breccia*, the gravel fragments are not rounded, but angular.

Cemented sand grains give rise to the porous formation known as sandstone. The

A microphotograph of a diamond, the hardest known natural substance

pores of this rock may make up as much as 30 per cent of the total volume. Liquids move quite freely through the pores. For this reason, sandstones are often reservoirs for petroleum deposits, as well as for groundwater. Silt particles are converted into siltstone; mud particles, into mudstone and shale.

ROCKS DERIVED FROM PLANTS AND ANIMALS

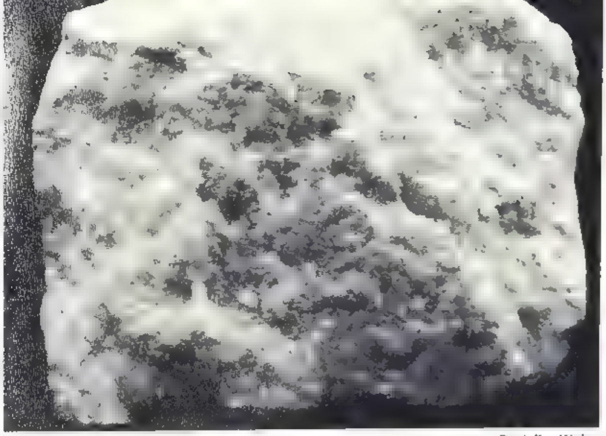
The commonest rocks derived from plants are the various varieties of coal. All coal started as green or woody material—the remains of plants that thrived ages ago in swampy areas. These remains were buried under later sediments. The various strata sank under ancient seas and rose periodically. Some were folded and broken up by crustal movements. As a result of tremendous pressure, heat, and the exclusion of air, the organic materials were transformed in the course of time into coal. Peat, lignite, bituminous coal, and anthracite are successive stages in this transformation.

Animal remains have contributed to the formation of various familiar kinds of sedimentary rocks. Coral reefs and islands represent the skeletons of countless coral polyps and other organisms. One generation of coral after another has contributed to these huge deposits.

The rock called limestone is comp of calcite, or calcium carbonate, a mi compound of calcium, carbon, and oxy Calcite is commonly found in the shel animals such as snails, clams, brachiop and other shellfish. These shells may into the making of limestone. Much of t rock formation, however, is made up of c cium carbonate that has been precipita directly from solution in water. There marine and freshwater limestones. As waters retreat, limestone deposits becom part of the rocks on land.

EVAPORITES

Some sedimentary deposits have been formed from salts that have precipitated, or separated, out of solution in evaporating water. These sediments are called evaporites. They may develop from seawater or from the water of streams and lakes. Many of the salts in question are found in both oceanic and inland waters. Their concentrations may differ, and the mineral deposits they form may differ accordingly. Evaporites indicate dry, hot conditions. An arm of the sea may be cut off and become a lake of concentrated brine as the water evaporates. Once evaporation starts, the least soluble compounds precipitate first. In deposits derived from a body of seawater, calcium carbonate and iron oxide form the first, or



Dr Julius Weber

Marble (above) is a metamorphic rock. Sculptors often use it, as Michelangelo did in his creation of the *Pieta* (right).

© Joachim Messerschmidt, Bruce Coleman Inc

lowest, layer. Then comes gypsum, a sulfur-oxygen compound (sulfate) of calcium. Common salt, or rock salt, is the next to precipitate. Afterwards come various other compounds, such as sulfates of magnesium and sodium. These four groups of dissolved minerals, if present together, would form successive layers of evaporites from the bottom up. If dry conditions last, the deposits remain. Otherwise, returning waters or rain will redissolve them or cover them over with layers of mud and sand.

Sodium nitrate—a compound of sodium containing oxygen and nitrogen—forms vast evaporite deposits in the deserts of northern Chile. This nitrate was originally produced by certain bacteria in plants. Then water flooded the region and dissolved the nitrate from the soil.

FOSSILS

As sediments accumulate, they may contain remains of dead organisms. These turn into stone or leave their imprints in the rocks formed from sediments, and so become fossils. Scientists study them to discover the evolution of life through the ages. All known fossil-containing sedimentary rocks, arranged layer on layer, make up what is known as the *stratigraphic column*. It is the geologist's historical standard, used to date geological events.

METAMORPHIC ROCKS

The third great division of rocks—the metamorphic rocks—is made up, as we have pointed out, of igneous or sedimentary rocks that have been transformed within the earth's crust into rocks of a quite different sort. Generally some traces of the original rock structures have been preserved.

FORMATION

One of the most important factors in metamorphism—the formation of metamorphic rock—is pressure. It may be applied by overlying sedimenatry beds. It may be caused by magma making its way into surrounding rock layers. It may be due to the mountain-building forces that deform the earth's crust. As pressure is applied, tremendous heat is generated. This quickens the chemical reactions taking place and heightens their effects. The presence of water is another factor in metamorphism. The water may be so scanty that it forms a mere film around the particles. Yet it provides a medium in which rock substances can pass into solution and from which they can condense on the surface of new and growing crystals.

Under extreme heat and pressure, the original rock particles are forced into new arrangements. In some cases, the rock con-

Dr. Kurt E. Lowe

Jack W...

Slate (left) is a metamorphic rock. Squares of slate (above) m... attractive backyard terraces

stituents recombine with those in the immediate vicinity and form new minerals, many of which grow with nearly perfect crystal form. Garnet is such a mineral.

LAYERING

Metamorphic rocks may exhibit layers resembling those of sedimentary rocks. Metamorphic layering, or foliation, is due to mechanical and chemical changes in the original rock. Grains, crystals, and fossils are shifted or broken up and strung out in linear series. Parallel rows of platelike minerals, not at all related to the original bedding, may form. Shale is changed by pressure into slate. This may later become a rock called phyllite and, with continued pressure, a crystalline foliated rock known as schist. Other kinds of rock, such as sandy shales and granites, for example, are transformed into a more coarsely foliated, crystalline rock called gneiss.

Slate is a dark rock with an invisibly fine grain. It splits readily into thin smooth slabs. Phyllite represents a stage intermediate between slate and schist. Its grain is very fine, consisting primarily of mica, but here and there a few larger crystals appear. The foliation is rougher and wavier than that of slate. Schist is visibly crystalline, with wavy foliation. It consists of such flakelike or tabular minerals as mica, chlorite, hornblende, or talc, as well as distinct crystals of quartz and garnet.

Gneiss looks irregular and st... because it has alternating layers of diffe...nt minerals. Gneisses originate from sev...al different kinds of rock. Each type of gn...s has much the same composition a... mother rock. Granite gneiss, for exa... is derived from granite.

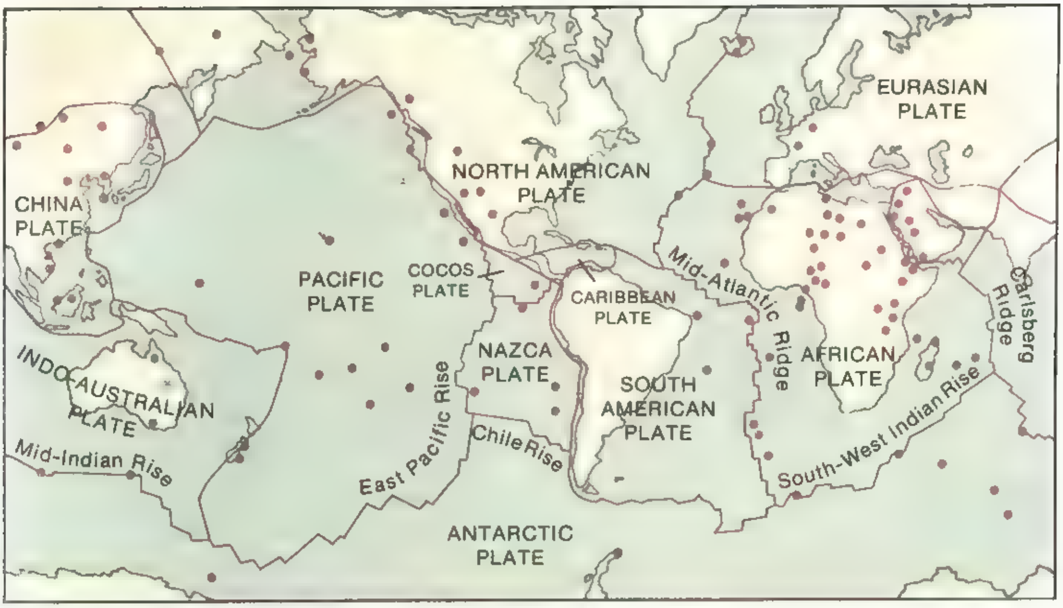
Other kinds of metamorphic rock s... no foliation at all. Pure sandstones ... changed into a more compact mass ca...d quartzite, where pore spaces have been compressed, making a very hard and d... ble rock. Limestone is converted by h... and pressure into marble, where the ... bonate grains become visibly crystalline. Pure marble is white. Most limestones, however, contain impurities that often react under metamorphism to produce new minerals. These often impart striking colors or mottling to the resulting marble, making it more attractive as a building stone. Marble is very plastic under pressure.

METAMORPHISM IN REVERSE

Metamorphism in reverse also occurs. Once the transforming forces cease, metamorphic rocks tend to return to their original unaltered condition. Rocks may be remelted into magmas. The whole cycle then begins anew, for the rock-forming processes described above are still going on. New rocks are replacing those destroyed by the effects of air and water in a continuing geologic cycle.

PLATE TECTONICS

by J. Tuzo Wilson



The theory of plate tectonics holds that the earth's crust is made up of six large and several small rigid plates that move slowly relative to one another, carrying the continents. Plate tectonics is a refinement of the older theory of continental drift.

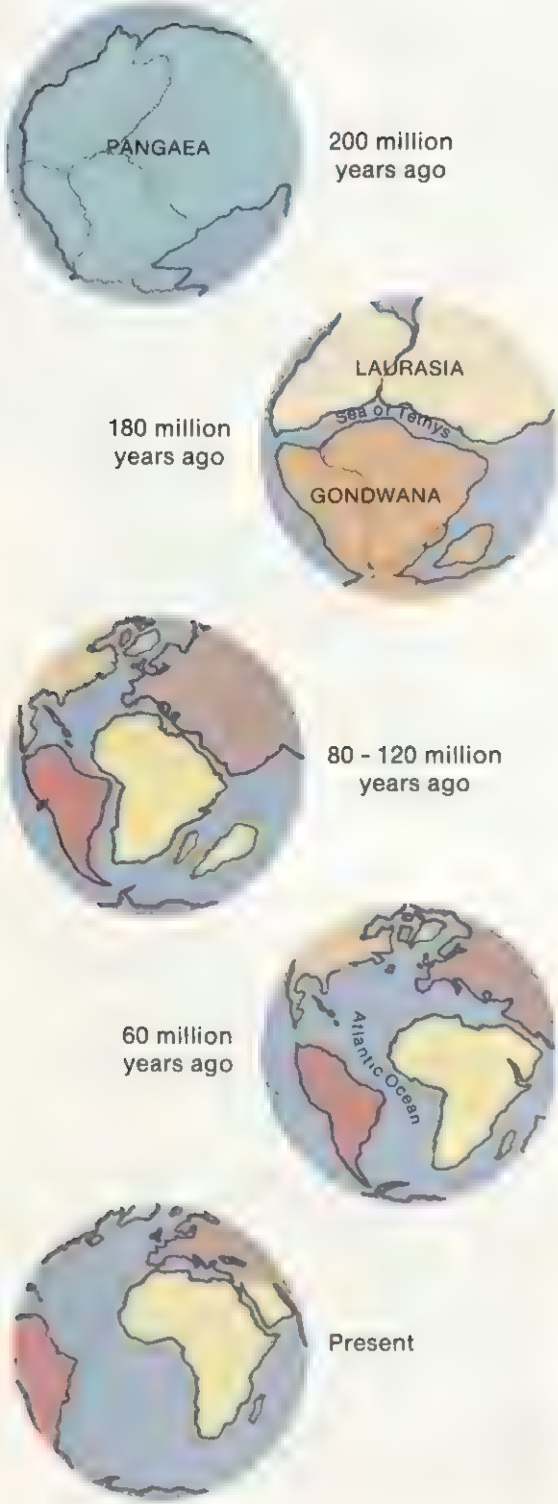
JIGSAW PUZZLE–that's what many people think of when they look at a map of the world. Push Europe and Africa over across the Atlantic and the coastlines fit–fit very well–against the coastlines of the Americas. Move India, Australia, and Antarctica around and you find that their coastlines also fit together. Like pieces in a giant jigsaw puzzle.

After the Americas were discovered and mapped centuries ago, several learned men noticed that the opposing coasts along the Atlantic had shapes that would fit together. They proposed that early in the earth's history the continents had been joined and that later they had been violently torn apart. In the 19th century this idea was supported by studies of the geology and life forms on both sides of the Atlantic that revealed many similarities–some dating from times long after the origin of the earth and indeed as recently as the age of dinosaurs some 150,000,000 years ago.

Studies such as these led Alfred Wegener, a German meteorologist, to propose in 1912 the theory of continental drift.

CONTINENTAL DRIFT

Wegener believed that the opening of the Atlantic, Indian, and Southern oceans was not due to any early cataclysms but rather had occurred slowly and gradually in the center part of geologic time. He supported the admitted similarities of shape, geology, and some living forms on opposite coasts with arguments from surveys that purportedly showed that Greenland was moving relative to Europe at a measurable rate. He further theorized that because the earth is a rotating sphere there exists a



force that pushes continents toward the equator. The continents, he believed, plowed through rocks of the sea floor like a ship through water.

LITTLE SUPPORT

While biologists in particular agreed that the similarities were real, geologists and physicists disagreed with Wegener's other arguments and suggested that the similarities might have a cause other than continental drift. Some, for example, proposed that land bridges had once crossed oceans and were responsible for the similarities of life forms. Geologists also showed that the surveys were in error and that the forces on a spheroid are small and act in the wrong direction to explain Wegener's ideas. They further argued that even if the Andes in South America were formed like low waves before continents advancing westward, there were no signs of any break or disturbance along the eastern coasts of the Americas where the wake of the continents should have been seen. While these arguments did not entirely destroy the possibility of drift, they took away support for the theory. When Wegener died in 1930 very few geologists had accepted his idea.

The chief exceptions were some geologists in the Southern Hemisphere who were impressed by the particularly good match of coastlines across the oceans there. Some Alpine geologists were also impressed by the tremendous compression of hundreds of kilometers indicated by the folding and thrusting of some rocks over others in the mountains. The rest could see little need for the theory and no mechanism to explain drift on a solid earth.

EARLY CLUES

About the time of Wegener's death several geologists made observations that suggested a mechanism for and provided an explanation of continental drift. They realized that the slow radioactive decay of sev-

At left, we show what some geologists think may have occurred as one giant landmass, "Pangaea", broke apart during geologic time.

eral naturally-occurring elements in the earth produced much heat—enough so that the earth, although largely solid, is white hot inside, hot enough to deform rocks. The rocks could then be slowly deformed to generate convection currents in the earth's interior. The currents would be like those in a pan of water heated on a stove, but incredibly large and slow. These geologists further proposed that these currents might be rising under ridges then known only vaguely to occur along the central axes of oceans; that they might be turning down again under active mountains and deep ocean trenches like those off Chile, Peru, and East Asia; and that they might carry the continents along at rates of about 5 to 10 centimeters a year.

These suggestions were vague and little regarded, and most scientists continued to reject the theory of continental drift. But then in the decade between 1956 and 1967 new discoveries revived it in a new form called plate tectonics.

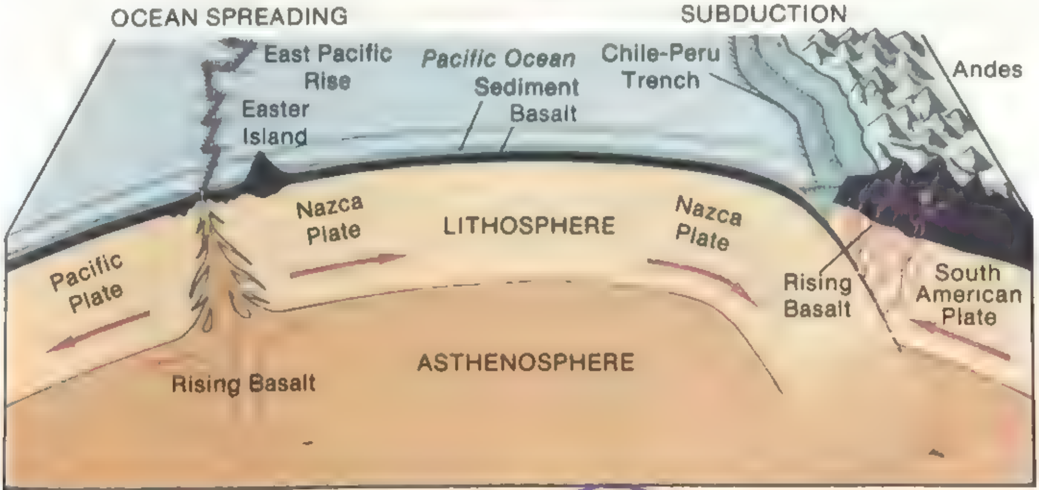
MAGNETIC CLUES

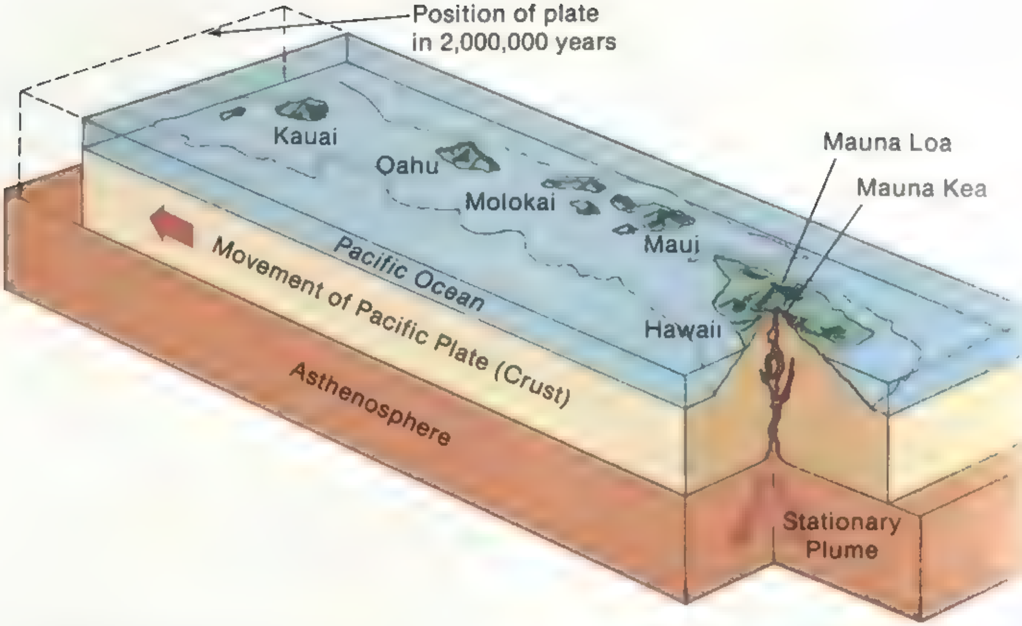
Around 1956 two discoveries turned the tide in geological thinking. One was the finding that the past motions of continents could be traced through an analysis of the magnetism of the rocks on the continents. The second discovery was that there is a continuous mid-ocean ridge throughout the world's oceans.

Since ancient times it has been known that a few rocks, chiefly iron ores, are natural magnets and can be used as compasses. As time went on, instruments improved and it was found that most all rocks are magnetized—though more feebly than iron ores. Further it was discovered that rocks acquire their magnetism from the earth's magnetic field at the time of their formation and that they retain this magnetization tenaciously thereafter.

Thus lavas poured out near the earth's magnetic poles are magnetized as they cool in the same vertical direction as the field at the poles. Sediments accumulating in an ocean near the poles are similarly magnetized. One the other hand, rocks forming near the earth's equator where the magnetic field is horizontal are magnetized in that direction. And so through other areas of the earth. Rocks are magnetized in a direction appropriate to the latitude of the place where they form, and they retain that direction of magnetization.

Geologists think that molten material rising from the earth's mantle at mid-ocean ridges creates new crust. Older ocean floor is then pushed down (subducted) beneath colliding plates into deep trenches like those off Peru and Chile.





A mid-plate volcanic island is formed when hot magma forces its way through a "plume" to the surface. The older Hawaiian islands in the chain trace the motion of the Pacific plate.

Around 1956 it was discovered that rocks of recent origin on several continents were magnetized in directions corresponding to their location, but that rocks known to have been formed at successively older times showed progressively different magnetic orientations. Further it was found that the orientation changes were just what would be expected if the the continents had been moving in the way Wagener and his few followers had proposed. This was striking proof for the theory of continental drift.

MID-OCEAN RIDGE

The second discovery—of a continuous mid-ocean ridge throughout the world—pointed to a possible mechanism explaining the movement. In 1956 U.S. geophysicist Maurice Ewing and others began detailed investigations of the ocean floor. Evidence accumulated over several years suggested that a great broad mountain system lay down the center of the Atlantic Ocean from the Arctic to the Southern Ocean. There, this system, called the mid-ocean ridge, turns to the Indian Ocean. In the middle of the Indian Ocean branches, one branch going into the Gulf Aden and the Red Sea and the other pas ing mid-way between Australia and Antar tica to cross the Pacific and enter the Gul of California. There it forms the San An dreas fault and emerges again off the coast of Canada as far as Alaska. A faulted, or cracked, valley—a rift—follows the crest of the mid-ocean ridge in most places. Shallow earthquakes occur all along the axis in all oceans.

SEA-FLOOR SPREADING

By 1960 ships had surveyed all of this ridge. Based on accumulated evidence, geologist Harry Hess of Princeton University revived the idea that the crest of the ridge is where the ocean floor spreads apart. He proposed that as the two sides spread apart intrusions of hot lava from beneath the crust create new ocean floor. He combined this with the idea that the surface crust, being cool and brittle, could slide, carried by very slow currents in the earth's hot interior, until it breaks again. Then one

piece could be overlapped and carried down beneath the other side of the break.

This activity occurs under active mountains, ocean trenches, and island arcs. The theory explains why a second great belt of earthquakes marks these areas around the world, rimming the Pacific and following the Himalayas and Alpine Mountains across Eurasia. In places where the brittle crust is forced down deep into the interior it may break. This explains why the only earthquakes observed to occur deep in the center are beneath these areas to depths as great as 700 kilometers.

SIX LARGE PLATES

By 1965 further investigations led to the proposal that the earth's surface is broken into six large plates and several smaller plates. It was further suggested that these plates are rigid and that their boundaries are marked by earthquakes where the plates move and also often by volcanoes.

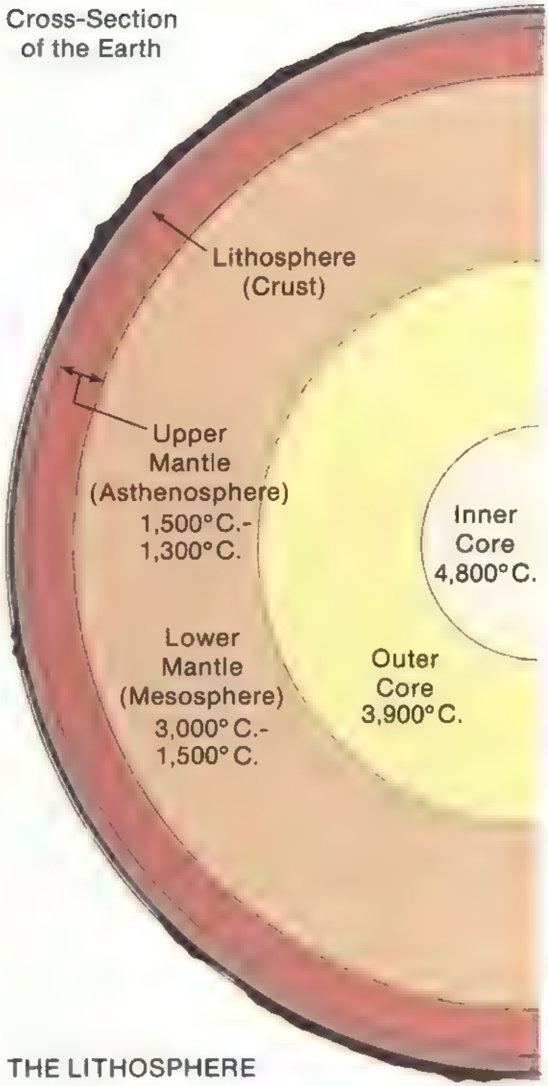
Where plates separate and new ocean floor is created, mid-ocean ridges are the boundaries. Where plates collide and overlap, young mountains and arcs and trenches are the boundaries. Where two plates slide horizontally past each other, a boundary called a transform fault occurs. The San Andreas fault system is a transform fault between the American and Pacific plates.

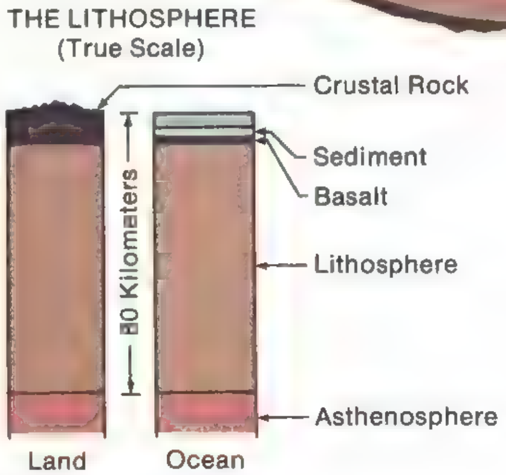
The three types of boundaries join together in a network to break the whole crust of the earth into a series of plates. This system and its motion is called plate tectonics.

One should point out that a theorem in geometry shows that the relative motion of one part of the shell of a sphere relative to another part is always a rotation about poles and an axis which can be defined. Therefore the plates move relative to one another.

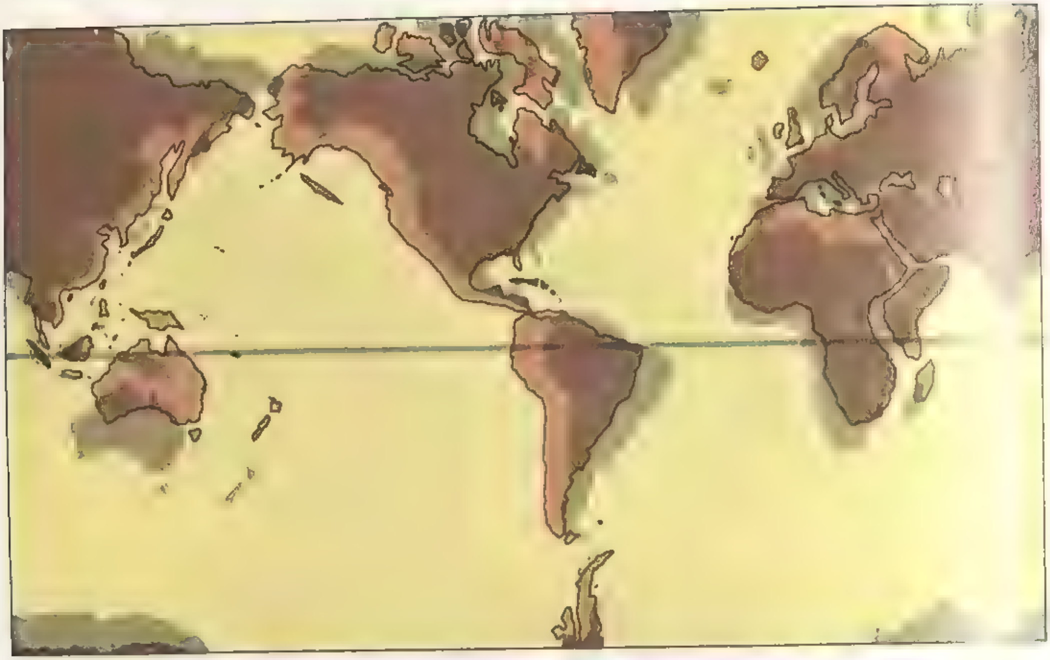
RAFT CONTINENTS

Plate tectonics differs somewhat from continental drift. Continental drift suggests





Right: the layers of the earth, from the inner core out to the crust.



This is what the earth will look like in 50 million years (black line) if the plates keep moving at their present rates Africa will be split in two, and California will be parked off the coast of southern Alaska.

that each continent moves like a ship through the ocean floor. Plate tectonics holds that the continents are like rafts frozen in the ice of a flowing stream, carried along with surrounding ocean floor in huge plates.

There are six major plates: the American, the African, the Eurasian, the Antarctic, the Indian, and the Pacific. The American plate comprises North and South America and the floor of the western half of the Atlantic. The African plate contains Africa and much surrounding ocean floor. The Antarctic plate has Antarctica and surrounding sea floor; the Eurasian plate, Europe, Asia, and nearby sea floor. The Indian plate has India, Australia, and all the sea floor between them. The Pacific plate underlies the Pacific.

MAGNETIC STRIPES

Studies of the oceans continued, and new discoveries allowed the theory of plate tectonics to be further developed. Magnetic surveys over ocean basins revealed a regular pattern of stripes of alternately stronger and weaker magnetization on the floors of the oceans. In the early 1960's British oceanographers F. J. Vine and D. H. Matthews showed that these stripes are oriented parallel with the axes of mid-ocean ridges and follow the ridges around the earth. They recalled that the earth's magnetic field is known to reverse at intervals of time from a few thousands to a few million years long. This reversal means that the earth's field, without changing its direction, becomes weaker and weaker until it fades away to nothing—and then returns in an exactly reversed direction. What had been the north magnetic pole becomes the south magnetic pole and vice versa.

Vine and Matthews pointed out that the lavas coming up along the crest of the midocean ridge to form new sea floor would be magnetized as they cooled in the direction of the earth's field where they formed. These lavas would be added to the separating plates and carried away equally in either direction. When after a period of thousands to millions of years the field reversed, the lavas injected following the reversal would be magnetized in the reversed direction. This reversing magnetization would alternately strengthen and weaken the magnetic effect measured in surveys and would appear as a symmetrical striped pattern around the spreading sea-floor axis.

TIME SCALE

Enough measurements have now been made to provide a time scale of reversals and to date all of the ocean floors. The scheme is like that by which tree rings mark the stages of growth in a tree. It turns out that northwestern Africa began to separate from the eastern coast of the present-day United States about 180,000,000 years ago; that Africa began to move relative to South America about 160,000,000 years ago; and that no part of the present oceans is more than 200,000,000 years old.

MOUNTAIN BUILDING

The theory of plate tectonics also explains much about when and how active mountains like the Andes in western South America and the Cascades in western North America were built at the converging boundaries of plates. As two plates collide parts of the earth's crust are uplifted and folded with great compression and thrusting of rocks occurring. Earthquakes and volcanoes frequently occur. But what about older mountains—mountains no longer characterized by volcanoes, severe earthquakes, and other signs of young life, mountains like the Urals and Himalayas that lie in the middle of continents?

Magnetic studies suggest that the continents did not separate just once with the breakup of a gigantic landmass. Rather, continents have been breaking apart and separating and coming together and joining in different patterns for much of geologic time. This suggests that older mountains like the Urals and Himalayas may have once been on the edges of continents and may have been formed when different plates came together in the past. In other words, older mountains may mark the sites where plates once converged in the geologic past.

The Atlantic Ocean started to open about 180,000,000 years ago. It opened nearly along the line of closure of an earlier ocean. The sides of this earlier ocean—usually called Tapetus after the father of oceans in Greek mythology—came together some 600,000,000 years ago and raised up a mountain range. The opening of the Atlantic millions of years later tore this range into fragments. These fragments are now part of the Appalachian mountains in eastern North America, the mountains of western Morocco across the present Atlantic, mountains farther north in East Greenland, and the Caledonia Mountains of Scotland and Norway.

Werth © Longview 1980/Woodfin Camp

The eruption of Mount St. Helens in 1980 probably resulted from plate motion—one plate sliding under another, feeding hot magma into St. Helens.

VOLCANOES

The theory of plate tectonics can also explain other geological occurrences—volcanoes, for example. Most volcanoes occur, as we have noted, along plate boundaries. They occur at separating ridges—for example, in Iceland, the Azores, and Tristan da Cunha, along the mid-Atlantic ridge.

Dick Rowan, PR

Hawaii is one of the most active hot spots on earth. Here we see Mauna Loa erupting. Fiery lava flows outward as the crater itself smokes.

Or they occur along converging plate boundaries, as in the Andes where the American and Antarctic plates are converging. A few have erupted in the middle plates: in Hawaii, for example, and the hot springs and now-dormant volcanoes of the Yellowstone Park area in western North America. What causes these?

It has been suggested that, besides great, slow convection currents that carry plates about the earth, there are also smaller, somewhat more rapidly rising jets or plumes of hot material rising in the mantle of the earth. (The earth is believed to be composed of an inner solid core; middle mantle that is at least partially molten; and an outer crust.) These plumes, often called hot spots, can be likened to smaller and more active thunderheads or tornadoes associated with a much larger advancing weather front.

Most of the isolated, mid-plate volcanoes like those of Hawaii and the Yellowstone area lie at one end of a line of extinct volcanoes, which get steadily older with distance from the active center. Thus Hawaii itself with its two active volcanoes, Mauna Loa and Kilauea, is at the extreme southeastern end of the chain of the rest of the Hawaiian islands, which become steadily eroded and older to the northeast. Likewise Yellowstone is at the eastern end of a line of extinct volcanoes extending into the Snake River and Mountains of the Moon in Idaho. These chains of extinct volcanoes have been likened to smoke that the wind is carrying away from a chimney.

The theory of plate tectonics, with the aid of magnetic imprinting, allows the rate and direction of movement of any plate to be found relative to any other plate. If one plate—say the Antarctic—is considered stationary relative to the deep interior of the earth, the date and direction of all other plates can be determined. An analysis of seafloor spreading has been used to do this. It turns out that the motions of the Pacific plate are compatible with the direction of the Hawaiian chain and the ages of the islands. Plate motion has slowly moved the volcanoes—and islands—away from the hot spot that created them. In other words, the Hawaiian island chain traces the motion of the Pacific plate.

In some spots mid-ocean ridges produce more lava than in other parts and island volcanoes form—as in Iceland. These spots may also be hot spots. In these cases, however, two ridges may form, one on each of the two separating plates. Ridges extend from Iceland, which straddles the Mid-Atlantic Ridge, westward to Greenland on the American plate and eastward to the Faeroe Islands in the North Atlantic on the Eurasian plate. Similarly, ridges extend from the active volcanic island of Tristan

de Cunha westward to South America and eastward to Africa.

Hot spots also occur at the junction of some plates. Examples are the Azores where the American, Eurasian, and African plates meet, and Macquerie Island south of New Zealand, where the Pacific, Antarctic, and Indian plates meet. Some geologists find this significant. They propose that, although hot spots do not drive plates about, they may perhaps help to determine the lines along which plates fracture and separate.

ARCS AND TRENCHES

If the theory of hot spots and relative motions is correct, it has other possible consequences. Where ocean floor is being carried down freely into the interior, it is likely to do so along circular arcs. This is so for the same reason that if one pushes one's thumb into a dead tennis ball the depression is circular. Geometry dictates this pattern. This may explain the origin of the dozen or so circular island arcs on the earth—such as the Aleutians.

If, on the other hand, a continent overrides an ocean floor, which is itself stationary, it will force down the floor in a trench directly off the coast. An example of this may be the deep trenches off Peru and Chile.

PRACTICAL USES

The theory of plate tectonics, which has now been generally accepted by geologists, has several practical applications. It tells, for example, much about the cause and distribution of earthquakes and where they can be expected to occur. Although no one has yet been able to predict the exact time of a major earthquake, intensive research in earthquake prediction is going on and such forecasts may become possible.

The theory also throws light on where and in what way many mineral deposits may have formed. Many important petroleum deposits lie near coasts, both on and off shore. These deposits can be seen to have begun to accumulate when the particular ocean started to form, so the oldest rocks—and the chances for petroleum finds—can be predicted even before drilling begins. Knowledge of plate motions can also explain many other features of petroleum basins.

Ontario Science Centre

Canadian geophysicist J. Tuzo Wilson proposed the theory of hot spots, which explains the distribution of mid-plate volcanoes

Exploration of mid-ocean ridges has disclosed streams of hot waters bearing abundant metals in solution pouring out of the rift in some places—in the Red Sea, off the Galapagos Islands, and in the Gulf of California, for example. These discoveries have helped explain the source of elements found dissolved in sea water or precipitated from it, such as manganese nodules on the sea floor. They also help explain how ore bodies form. More underwater mineral sources will undoubtedly be found and some may be exploited either as sources of minerals or as sources of heat and energy.

AND SO THE PUZZLE FITS

And so the pieces of the jigsaw puzzle fit—and we know why. In a few years the theory of plate tectonics has for the first time provided a comprehensive theory of the behavior of the earth—an essential to understanding our home in space.

EARTHQUAKES

It is hard to realize that the crust of the earth is constantly changing. Yet the fact is that gigantic forces are continually at work shaping and reshaping the rocks of the crust—thrusting them up into enormous folds, twisting them, and cracking them. This process is generally slow, and we are rarely aware of it. But sometimes a major earthquake takes place. The earth shakes violently; long cracks are formed on its surface; monuments topple; buildings crash; hundreds or even thousands of people die. It is then that we become aware of the tremendous forces at work under the earth's surface.

Although destructive shocks are comparatively few in number, earthquakes are a common occurrence. If we include in our reckoning all shocks from the very greatest to the very smallest, something like one million quakes take place every year. Furthermore, as far as we know, they have been occurring in great numbers from the earliest times in earth's history. Certainly the written records of mankind often refer to them.

There have been many fanciful earthquake legends. They are hardly more fantastic than the theories about quakes that were advanced by learned men in the past. In our own day, however, on-the-spot investigation and the use of precision long-range instruments have gradually lifted the veil of mystery. The study of earthquakes now forms a distinct science, known as *seismology*, from two Greek words meaning "earthquake science." Those who devote themselves to this science are called *seismologists*, or "earthquake scientists."

CAUSES

Earthquakes may be caused by a single mechanism or by a combination of mechanisms. These causes are generally classed into four categories: (1) tectonic, (2) volcanic, (3) man-made, or artificial, and (4) miscellaneous.

TECTONIC MOVEMENTS

The majority of earthquakes are caused by tectonic processes—by movements along *faults*, or cracks, in the earth's crust. In these movements a segment of the earth's crust along one side of a fault moves past a segment on the other side. This process is believed to account for most earthquakes near the earth's surface.

A recent theory about the earth's crust—known as the theory of plate tectonics, continental drift, or sea-floor spreading—may provide an explanation of tectonic earthquakes. According to this theory, new rocks of the earth's crust are continually being formed. The rock material arises from deep within the earth and emerges along ridges on the sea floor. As this material rises along a mid-ocean ridge, it causes the ridges to spread apart—a phenomenon known as sea-floor spreading.

Many scientists also believe that the earth's crust is divided into a number of plates, and that these plates are in motion relative to one another. New material formed in the ridge areas pushes the plates apart in that area. As the plates are spread apart at the site of a mid-ocean ridge, they converge in other parts of the earth. Where continental and oceanic plates come into contact, the leading edge of the oceanic plate is subducted, or displaced downward, under the continental plate. This subduction zone is responsible for a good deal of high-intensity seismic activity, and is generally classed as a high-risk area as far as earthquakes are concerned. Any area of contact between plates—the point at which one plate must "give" to the other—is an area where earthquakes are likely to occur.

VOLCANIC ERUPTIONS

Certain earthquakes are not tectonic, but are associated with volcanoes. They are due to explosions or to fractures occurring within the structure of a volcano. These

Photo revealing how a severe earthquake in Anchorage, Alaska, buckled paved roads and collapsed buildings. The quake was also felt on the Californian and Hawaiian coasts as tidal waves.

volcanic earthquakes may be violent in the vicinity of a volcano, but their effects are not felt at any considerable distance.

Volcanic earthquakes are generally small-to-moderate in intensity. They are believed due to *magma*, or molten rock, moving up through the earth's crust. Earthquakes of this type often provide a warning that a volcanic eruption is about to occur.

MAN MADE QUAKES

It was found, quite by accident, that man's activities could initiate small-to-intermediate intensity earthquakes. In 1961, the U.S. military used a deep well to dispose of radioactive materials. A short time later, tremors were felt in the vicinity; in fact, 1,600 tremors were recorded in a seven-year period. It was concluded that the liquid injections into the deep well and the occurrence of quakes were related. Similar phenomena have been recorded when fluids were injected into oil fields to enhance oil production.

Underground nuclear testing also produces tremors of small-to-intermediate intensity. It is not known, however, whether a large atomic blast could initiate a large-scale earthquake.

MISCELLANEOUS

A number of other factors may also play a role in causing earthquakes. Studies indicate that, in some instances, a relationship between rainfall and ground water and earthquakes exists. Meteorites hitting the earth may also play a role.

THE QUAKE ITSELF

The stresses and strains within the earth's rock structure, whatever their cause, are a long time in building up. Finally even a slight additional force may prove to be the straw that breaks the camel's back. It may cause a rupture in the rocks to take place. Most earthquakes, as we have pointed out, seem to be caused by sudden movements along faults. Because they are pressed together and because of friction, these blocks of rock do not travel freely along the crack surface. In fact, they are virtually locked together and, as the earth forces act, they do not move at first. Great strains build up in these bending rocks. As

their elastic limit or breaking point is reached, they shift suddenly parallel to the fault surface. They "snap" into their new positions, and the sudden jar causes an earthquake.

The place in the rock structure where movement takes place is called the *focus*. The point of the earth's surface directly above the focus is the *epicenter*. The foci (plural of focus) of earthquakes have been located at various depths, from near the surface to 800 kilometers and more beneath the surface.

Movement creates a disturbance that has been compared to the infinitely slighter one that is caused when a pebble is dropped in a pond. When a snap in the earth's crust takes place, the disturbance takes the form of ever widening waves. These differ, however, in various respects from the ripples in a pond. For one thing, they make their way through the body of the earth, and not merely over its surface. Again, they travel in two groups through the earth, and these groups move at different rates.

COMPRESSION WAVE

The first and faster wave is called the *compression wave, primary wave,* or *P wave.* It results from changes in the volume of the earth particles at the fracture in the crust, as they are alternately condensed and expanded. These condensations and expansions are transmitted through the earth at an average speed of eight kilometers per second. The exact speed depends on nature of the strata through which the wav is traveling. The earth particles oscillate, o move back and forth, in the direction which the compression wave is traveling is therefore often called a *longitudin wave.*

SHEAR WAVE

The second earthquake wave is called the *shear wave* or the *secondary,* or *wave.* The shear wave of an earthqua travels out in all directions. It causes t earth particles to vibrate at right angles is therefore sometimes called a *transv wave.* It travels at an average speed of fi kilometers per second. As in the case the compression wave, the exact rate speed depends on the medium throug which the wave travels as it moves ou from the focus of the quake.

EFFECTS

The motion of the earth's crust cause by earthquake waves may be so slight th they will not be felt by anybody. We com to know of them only because they are re corded on a certain delicate instrument called a *seismograph.* In other cases the quakes may be distinctly felt. They may cause a certain amount of swaying and rat tling, but they will not bring about any visible changes in the surface of the earth, nor will they cause any considerable amount of damage. By far the largest number of earth-

Severe quakes—like this Nigata, Japan, quake in which apartment houses toppled—cause serious aftereffects: fires, contamination of water, and landslides
NOAA/National Geophysical and Solarterrestrial Data Center

quakes are of one or the other of these two types.

In other quakes, however, the shaking of the earth is more violent. The ground begins to lurch this way and that. If the quake is unusually severe, houses and other structures may be displaced from their foundations, or they may crash to the ground.

In severe quakes there may also be notable changes in the outer surface of the earth. Cracks may form in the earth's crust. The adjoining sections along these rents may be displaced horizontally as much as six meters. The surface may also be displaced vertically: one section of it may be raised above an adjoining section. Gaps may also be formed in the earth, but these are generally of comparatively slight depth.

SOUNDS

The sounds that accompany an earthquake are generally awe inspiring. Many of these sounds do not come from the earth at all. They represent the violent creaking of buildings and the deafening crash of bricks, masonry, plaster, and the like. Other sounds, however, actually arise in the ground. The vibrations set up by the rupture of the rocks are transmitted to the human ear.

The ear can detect such vibrations only if they fall within a certain range of frequencies. The lowest frequency that is audible to the average person is something like twenty vibrations per second. Some earthquake waves have frequencies below those that are audible to man. In cases where the frequencies of earthquakes are audible, they are generally not far above the human threshold of hearing, and therefore are low-pitched.

SMALL TREMORS

Sometimes preliminary tremors, called *foreshocks*, are felt before the principal shock or shocks. After a severe earthquake the ground near the epicenter may continue to be disturbed by a series of minor quakes, called *aftershocks*. They may continue for months or years after the main quake.

The secondary effects of earthquakes may be deadly. Fire may break out because of broken gas mains and pipes or electrical short circuits. The shaking of the earth may prove to be the trigger force that will cause landslides.

BODIES OF WATER DISTURBED

Thus far we have been talking about quakes that make themselves felt on land. Quakes also take place in great numbers in the ocean areas of the earth, which make up some three quarters of the earth's surface. A quake felt at sea is called a *seaquake*. To those on ships in the vicinity of such disturbances, it seems as if the vessels are pounding some submerged obstruction, like a reef. Ships' officers generally report these seaquakes, giving the latitude and longitude where they occurred.

Earthquakes may have strange effects on standing bodies of water. The latter may develop long oscillating waves known as *seiches*, which often occur in lakes and bays. Most spectacular are the huge waves generated in the sea by some earthquakes. Some of these waves are caused by quakes originating inland. Perhaps submarine landslides induced by some inland earth tremors disturb the sea. Other giant ocean waves are due to displacements of the seabed along faults. The waters seem to withdraw and then rush back with great force. However, by the time the waves have traveled great distances they are small. Waves set up by submarine earthquakes are popularly known as *tidal waves*. This term is not accurate, of course, since these waves are not due in any way to the lunar or solar attraction that brings about the tides. A more accurate name is *seismic sea waves*. The Japanese call the waves *tsunamis*. This name has been widely adopted by seismologists.

Tsunamis can travel great distances and at a high rate. The wave that was caused by the seaquake off the Aleutian Islands on April 1, 1946, reached Valparaiso, Chile, some 12,000 kilometers away, in 18 hours. This indicates that its speed was about 660 kilometers an hour.

Tsunamis cannot be observed on the high seas. For one thing, the total volume of

LIST OF FAMOUS EARTHQUAKES

Date	Site	Description
1755	Lisbon, Portugal	Three shocks razed large part of city; seismic sea wave and fir added to destruction. Over 20,000 dead.
1783	Calabria, Italy	Six major shocks in February and March Many towns raz 60,000 lives lost. Hundreds of aftershocks.
1811–12	New Madrid, Missouri	Series of violent quakes. Landslides; some areas lifted up others depressed. Effects noted as far east as Boston.
1886	Charleston, South Carolina	Worst earthquake that ever occurred on Atlantic coast. D turbed area, almost 7,800,000 square kilometers. Dama comparatively small over most of this area; but Charlesto suffered considerable loss.
1887	Sonora, Mexico	Quake elevated a portion of the mountain range there. Man towns and villages in the valleys destroyed.
1897	Assam, India	Hills of Assem elevated from 1.5 to 6 meters. Almost all ma sonry edifices in region flattened; forests destroyed; jungl and farmland flooded.
1905	Kangra, India	Quake in foothills of Himalayas, in province of Punjab. Felt over area of 3,900,000 square kilometers. 20,000 lives lost
1906	Formosa	Horizontal and vertical displacements involved. 1,300 killed over 7,000 buildings destroyed.
1906	California	Crust of earth rent for distance of more than 400 kilometers In San Francisco fire caused more damage than quake. Total loss of life throughout stricken areas about 1,000.
1908	Messina and Reggio, Italy	Cities partly destroyed. Damage due chiefly to poor construc tion of buildings and narrowness of streets. Seismic sea wave added to damage. Loss of life estimated at from 100,000 to 125,000.
1920	Kansu, China	Hundreds of cities and towns destroyed; number of dead esti- mated at over 200,000.
1923	Island of Honshu, Japan	Tokyo, Yokohama, and other cities hit by major quake. More than 140,000 killed, more than 500,000 buildings destroyed
1934	Bihar, India, and Kingdom of Nepal	Series of landslides and rockfalls in Himalayas. Many towns destroyed or damaged. Felt over area of almost 5,200,000 square kilometers.
1939	Concepción, Chile	Town of Concepción practically destroyed; twenty other towns devastated. About 30,000 killed.
1939	Central Turkey	Series of shocks, rocking nearly whole of Anatolia; numerous cities, towns, and villages destroyed. Number of dead esti- mated at 50,000.
1946	Dominican Republic	One of largest submarine quakes ever recorded; accompanied by seismic sea waves. Coastal sections devastated. Also caused great damage in Puerto Rico.
1949	Ecuador	Ambato and other cities partly destroyed; 6,000 killed.
1950	Tibet, China; Burma, India	Quake result of uplift in mountains of Tibet at eastern end of Himalayas. Felt over extended area of Tibet, China, India, and Burma. Geography of region considerably altered.
1951	Central America	In El Salvador, two towns destroyed; also did severe damage in Nicaragua.
1956	Northern Afghanistan	Many villages destroyed; over 2,000 people dead.
1957	Iran	Northern and western Iran ruined; 2,900 people dead.
1960	Chile	Many villages destroyed; 5,000 dead or missing.
1960	Morocco	Two quakes, resulting fires and tidal waves killed 10,000 peo- ple; city of Agadir ruined; 45,000 homeless.
1962	Northwest Iran	200 towns destroyed; 10,000 people killed.
1963	Skoplje, Yugoslavia	Most of city ruined; 1,000 killed; 18,500 homeless.

LIST OF FAMOUS EARTHQUAKES (continued)

Date	Site	Description
1964	Southern Alaska	"Good Friday Quake" (March 27) one of severest known; many towns badly damaged; more than 100 people dead or missing.
1966	Eastern Turkey	60 villages ruined; 2,477 dead; 100,000 homeless.
1970	Western Turkey	Town of Gediz largely ruined, as well as surrounding villages; more than 1,000 killed; 90,000 homeless.
1970	Northern Peru	One of worst quakes in recent times; perhaps 70,000 killed.
1972	Southern Iran	5,000 people killed; 45 villages destroyed.
1972	Nicaragua	City of Managua largely destroyed; more than 10,000 people dead.
1974	Northern Pakistan	Nine towns heavily damaged; 5,000 people dead.
1975	Eastern Turkey	Town of Lice and many villages destroyed; more than 2,000 killed.
1976	Guatemala	Guatemala City heavily damaged, most towns and villages in highlands destroyed; more than 23,000 people killed, more than 1 million people—or more than one-fifth of population—homeless.
1976	Northeast Italy	Nearly 1,000 people killed; more than 50,000 homeless.
1976	West Irian, New Guinea	Strong quake destroyed villages and killed hundreds; later quake-triggered landslides killed nearly 6,000.
1976	Northeast China	Tangshan earthquake, believed to be the greatest earthquake disaster in human history. Measured 7.8 on Richter scale; devastated 52 square kilometers; killed 750,000 people.
1976	Mindanao, Philippines	Strong quake and tidal waves kill more than 3,000.
1977	Indian Ocean	One of strongest quakes on record strikes off coast of Indonesian island of Sumba; huge tsunamis damage villages.
1978	Eastern Iran	City of Tabar demolished, killing about 25,000 people.
1978	Mexico	Dozens of people killed, hundreds injured in Mexico City.
1980	Northern Algeria	City of El Asnam severely damaged; 3,500 people killed.
1980	Southern Italy	Towns east of Naples heavily damaged; 3,000 killed.
1981	Southern Iran	Two earthquakes, two weeks apart, caused extensive damage in Kerman Province; more than 2,500 people killed.
1982	North Yemen	Major quake destroyed 21 villages; 2,800 killed.

UPI

A street scene in Managua, Nicaragua, shortly after a severe quake struck.

water that is affected is small compared with the volume of the ocean. Besides, the distance between the crest of one seismic sea wave and the next crest may be as much as 160 kilometers. But when a tsunami reaches the coast, the effects are apt to be devastating. This is particularly true if the shore is sloping. First, the water withdraws all along the shore, as if there were a phenomenally low tide. Then a solid wall of water returns and overflows the land. Whole villages have been destroyed by such waves, which may reach a height of 15 meters or more. Big vessels at anchor have been swept far inland and left stranded.

SIZE OF A QUAKE

Earthquakes are measured by magnitude and intensity. The magnitude of an earthquake is the amount of energy given off by the quake. The most commonly used method of measuring the magnitude of an earthquake is the Richter Magnitude Scale. It is based on measurement of the amount of ground motion as determined by a seismograph at known distances from the epicenter of the quake.

The earthquake that shook San Fernando, California, on June 25, 1971 caused extensive damage to underground structures, such as this storm drain.
U S Army Corps of Engineers

The magnitude is expressed in nu- bers from one to nine. The scale is a lo- rithmic scale. An increase by one wh- number on the scale indicates a ten- increase in the magnitude of the quake.

The intensity of an earthquake is measure of the effects of a quake. I based on observation. A widely used sc for measuring the intensity of an ea- quake is the Mercalli intensity scale.

THE SEISMOGRAPH

Fortunately seismologists have veloped an ingenious instrument that c detect the motion of the earth's cr caused by an earthquake even if it tak place thousands of kilometers away. Th instrument is the seismograph. With t device it is possible to register the shoc and motions of earthquakes and to dete mine where they arise. It is also possible obtain much valuable information about th strata through which the earthquake wav pass.

A seismograph is fundamentally a pe dulum. It is based on the principle tha because of its inertia, or resistance to changes in its motion, the heavy mass of the pendulum bob, at the end of the pendulum will remain still when the ground lurches underneath it. A recording pen attached to the pendulum bob traces out this quivering on paper that moves with the ground.

The recording paper is wound around a drum, which is kept revolving and also moving forward under the recording pen. As a result, the pen traces out a continuous line on the paper.

Actually, to avoid friction, the recording "pen" is generally a light spot that is reflected from a mirror, producing a fine black line on photographic paper. The almost imperceptible hills and valleys caused by the vibrations are greatly enlarged by a magnification process. A timing device marks the hours and minutes on each record.

To record the ground motion of a quake properly, three seismographs are required: a vertical one and two horizontal ones. If records of a quake are obtained on three such instruments, the distance from

the observatory to the epicenter of the quake can be calculated.

LOCATING THE EPICENTER

The time of arrival of the compression, or P, wave is read off from the recording sheet of the vertical seismograph. The time of arrival of the shear, or S, wave is similarly read off from one or the other of the horizontal seismographs. The time interval between the arrival of the P wave and the arrival of the S wave is determined. The distance of the quake is then found from a book of tables. Suppose, for example, that the S wave arrives at a given observatory 6 minutes and 40 seconds after the P wave. By consulting the tables, we learn that the arcual distance between the observatory and the epicenter of the quake is 4,900 kilometers. The arcual distance between two points on the earth corresponds to the shortest possible line connecting the points and following the curvature of the earth.

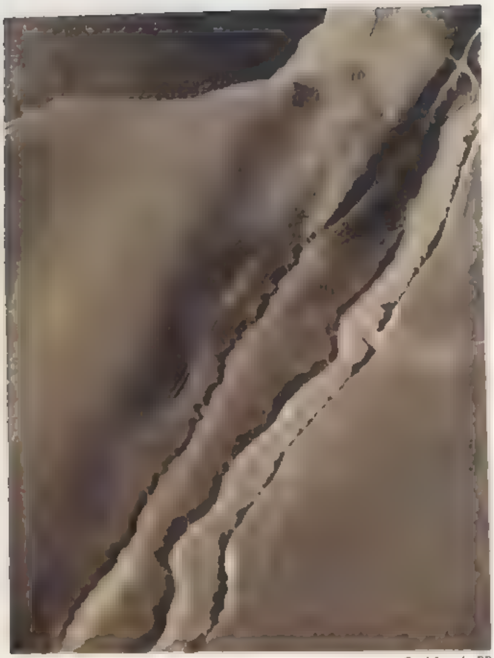
(C) Tom McHugh, 1972

The destruction of public roadways by earthquakes is both costly and inconvenient. It can also be deadly, particularly if it occurs during rush hours, when the streets are crowded.

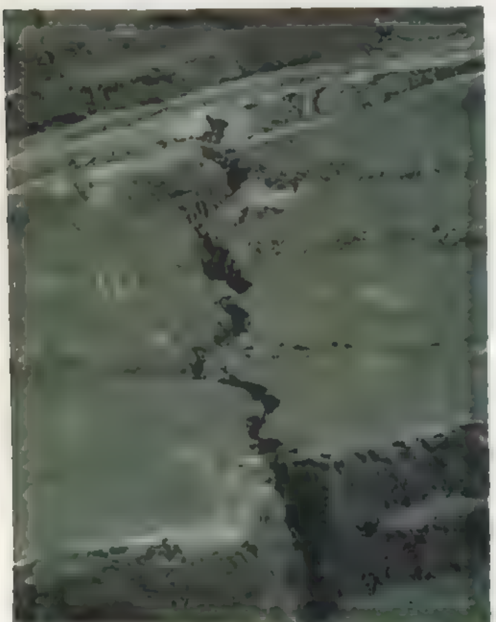
Even when we know the distance between our observatory and the epicenter of a given earthquake, our task is not complete. We know only that the quake is somewhere on the circumference of a circle with the observatory at its center and the distance from the observatory to the quake as its radius. To find out just where the

Earthquake intensity scale. This scale indicates the amount of surface damage caused by an earthquake (Modified Mercalli Intensity Scale of 1931).

- **I.** Not felt except by a very few under specially favorable circumstances
- **II.** Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.
- **III.** Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing cars may rock slightly. Vibration like passing of truck.
- **IV.** During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing cars rocked noticeably.
- **V.** Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
- **VI.** Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- **VII.** Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by car drivers.
- **VIII.** Damage slight in specially designed structures, considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.
- **IX.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously
- **X.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
- **XI.** Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps, and land slips in soft ground. Rails bent greatly by force of the shock
- **XII.** Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.



Carl Frank, PR



© Dr George Gerster, Rapho PR

Earthquakes sometimes cause a small gap on the surface of the earth as the top photo showing effects of a severe quake in Peru reveals. The lower photo shows the San Andreas fault in California, an area where earthquake activity is likely to occur—according to some scientists—soon

quake is, we get in touch with two other observatories, which are at more or less widely separated points and which have also recorded the quake. We construct three circles on a map with the three observatories as centers and the distances from the epicenter of the quake as radii. The point where the three circles intersect is the epicenter.

PREDICTION

By the 1970s scientists had begun to develop methods of predicting earthquakes. One way of making such predictions is based on a measurable effect called *dilatancy*. Dilatancy occurs in rocks that are under pressure shortly before they break asunder in an earthquake. The word dilatancy refers to a dilating, or enlarging, of the cracks in such rocks.

In the late 1960s scientists in the Soviet Union began to notice that an unusual kind of squiggle regularly appeared on their seismographs shortly before earthquakes. The squiggle turned out to be an abnormality in the speed of one kind of seismic wave, the pressure wave. The pressure wave slowed down, remained at the slower rate for awhile, and then returned to normal. Shortly after, an earthquake occurred. Several scientists advanced the dilatancy-diffusion theory to explain this pattern.

According to this theory, as stress on rocks in a fault area builds up, the rocks develop networks of tiny cracks that fill with ground water. If the pressure on the rocks begins to build at a fast rate, the cracks begin to dilate, or expand, and the ground water drains out of them. The pressure waves travel slower through dry space than through liquid-filled space, and the seismograph consequently records a slowing down. But later, the water seeps back into the expanded cracks, and the pressure wave returns to normal. At this point the rocks, weakened by the wide cracking and by the renewed water pressure, break apart in an earthquake.

These tell-tale pressure changes can be measured at earthquake prediction stations, which have increased in number in China, the United States, and elsewhere. A gradu-

...ew of the city of Managua, Nicaragua, showing the very wide area of destruc-
...n caused by the 1972 quake. There were some 10,000 deaths

...al warping or bulging of the earth's surface observed before earthquakes is also probably the result of dilatancy.

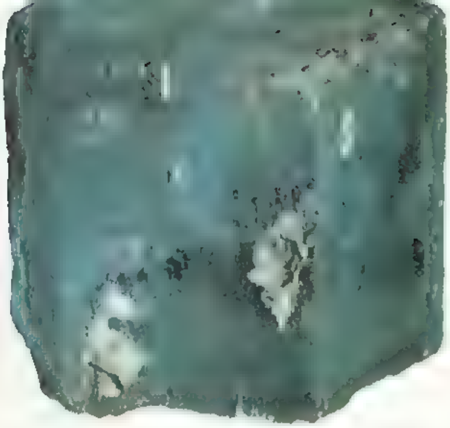
Other signs of a coming earthquake include variation in the water level in deep wells, and an unusually high content of the radioactive gas radon in well water.

Scientists have also speculated on some unusual prediction possibilities. For example, Chinese seismologists have long used observations of animal behavior in their prediction efforts. For unknown reasons, some animals seem to show unusual behavior patterns before a quake strikes. The validity and reliability of such behavior cues are far from established, however.

Still more unusual is the reported phenomenon of "earthquake light." Odd floods of light have long been described as occurring in the sky around the time of major quakes. Until recently, most scientists ignored such reports, but accredited accounts and photographs of the displays now exist. One possible explanation is that electric potential builds up in certain quartz-bearing rocks when they are placed under stress, as they would be along a fault about to give way. The potential might be released as an electric discharge, lighting up the sky. Here too, however, this possible line of research has not yet been adequately investigated.

MINERALS

by Frederick H. Pough



C. Nuridsany

Aquamarine is a gemstone variety of the mineral beryl. The crystals are characteristically large and hexagonal and have a blue or green tint.

sent compounds of carbon and oxygen with various metals. Carbonates are soft and dissolve readily in acids. The most important mineral of this group is calcite, or calcium carbonate, which often forms huge limestone masses. Another important rockmaker is dolomite, or calcium magnesium carbonate. Sometimes classed together with the carbonates are such minerals as the borates (compounds of various metals with boron and oxygen) and the nitrates (compounds of metals with nitrogen and oxygen).

(6) Halides. These are salts, in which metals are combined with one of the halogens, a group of elements including fluorine, chlorine, bromine, iodine, and astatine. Common rock salt, or sodium chloride, is the most familiar example. Halide deposits were often formed through the evaporation of the water—particularly sea water—in which they had been in solution. Since many halides dissolve easily in water, they are seldom found as minerals, except in dry climates or where they have been protected from the infiltration of water by impermeable rocks. They are commonly found together with calcium carbonate and various sulfates.

(7) Phosphates, tungstates, molybdates, uranates, vanadates, arsenates, and others. The representative minerals of this group are made up of oxygen plus nonmetals and metals such as phosphorus, tungsten, molybdenum, uranium, vanadium, or arsenic. A number of important ores are included here. For example, wolframite is an important source of tungsten; vanadinite, of the metal vanadium.

(8) Silicates. These consist of pounds of various elements with sili n and oxygen. They make up a considera proportion of the mineral species, and are the most important rock-builder all. They range from simple compou to very complex molecular and cryst structures. However, they all have in c mon the silicon-oxygen combinatio atoms.

The simplest member of the grou silica, or quartz, which contains only con and oxygen atoms in the ratio of to two. It is a very common mineral, suming a variety of forms, and is the c constituent of most sands. It is often fou scattered throughout rock bodies. The fe spars form a large group of metal silica found in many kinds of rocks. Other cates include the micas, the clays, talc, a asbestos. Certain silicates are classified gems; among these are garnet and zirc

MINERAL FORMATION

Minerals have been formed in vario ways. Certain kinds are derived directl from magma, or molten rock, which soli fies forming igneous rock. Quartz, mic and feldspars are good examples of roc formed in this way. Other minerals, such salt and sulfur, may be deposited as soli directly from the gaseous state, around vo canic openings. Wolframite, gold, quartz, and so on may be precipitated directly from solution in hot magmatic waters—steam and water arising from liquid rock.

The type of mineral deposit called the *vein* has been formed as circulating waters have dropped their loads of dissolved mineral matter in a crack in the rock. Among the common vein minerals are gold, quartz, and the sulfides. Occasionally the mineral-laden water will line a hollow, rounded space in the rocks with crystalline material. A hollow, crystal-lined boulder of mineral matter of this kind is called a *geode*.

Some minerals were originally in solution in bodies of water. They formed deposits as this water gradually evaporated. Among the most familiar minerals laid

down as deposits in this way are gypsum, other sulfates, and rock salt. Carbonates, borates, and nitrates have also been formed through the process of evaporation. Where the deposits are particularly extensive, it may be assumed that arid conditions once prevailed in the areas where they are found.

Certain minerals have developed from the alteration of pre-existing minerals that have been exposed to weathering. The oxygen contained in air and water often attacks the minerals in rocks, converting them into different compounds, such as oxides and sulfates. Some of these products are more soluble than the original materials and so they are eventually washed away into streams. In certain cases, minerals are mechanically broken down into smaller fragments, which are removed and further distintegrated by wind and water. These fragments later accumulate and may be cemented, forming sedimentary rock. When such cemented masses or, indeed, any kind of rock, are subjected to weathering and erosion, only the most durable and insoluble of the original substances may remain, to form deposits such as silica, clay, and bauxite (the ore of aluminum).

New minerals may arise from transformations of rocks brought about by heat or pressure or both—the transformations known as *metamorphism*. Crystalline calcite is formed as limestone undergoes metamorphism. The silicate olivine is converted into serpentine as it is acted on by hot water derived from magma. Metamorphic minerals may be elongated, needle-shaped, sheetlike, or platelike in form. Sometimes they are of striking size and beauty. Their forms and their positions in the rocks often reveal the intensity and directions of the forces that had acted on them.

A mineral, then, may be considered as the net result of natural forces acting on earth matter in an area through a given length of time. Few mineral forms and combinations persist very long, as geologic time is reckoned. One mineral is converted into another or reacts with another as it is affected by different processes.

Geologists map the surface distribution of minerals. They also study specimens from drillings of several kilometers' depth in the earth's crust. These investigations may serve practical ends, but whether or not this is the case, they help solve the mystery of the earth's origin and development.

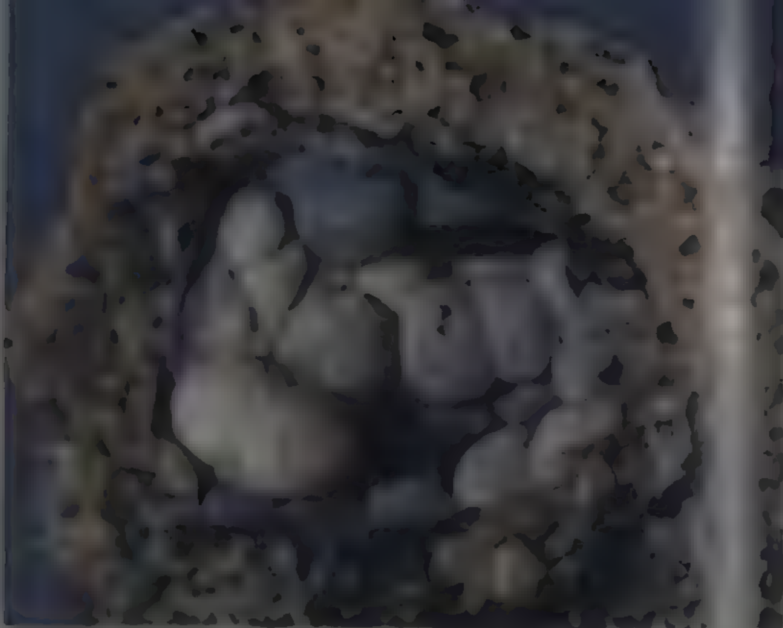
Ward's Natural Science Establishment, Inc

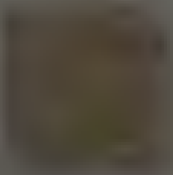
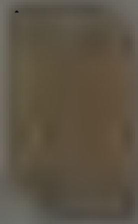
The gemstone lazurite, or lapis lazuli, embedded in marble. The mineral is a complex compound containing sodium, aluminum, silica, and sulfur.

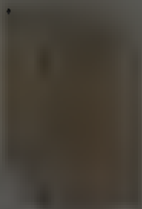
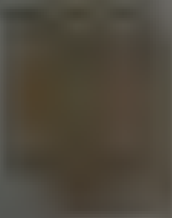
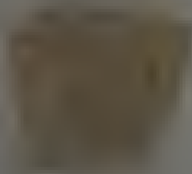
CRYSTAL STRUCTURES

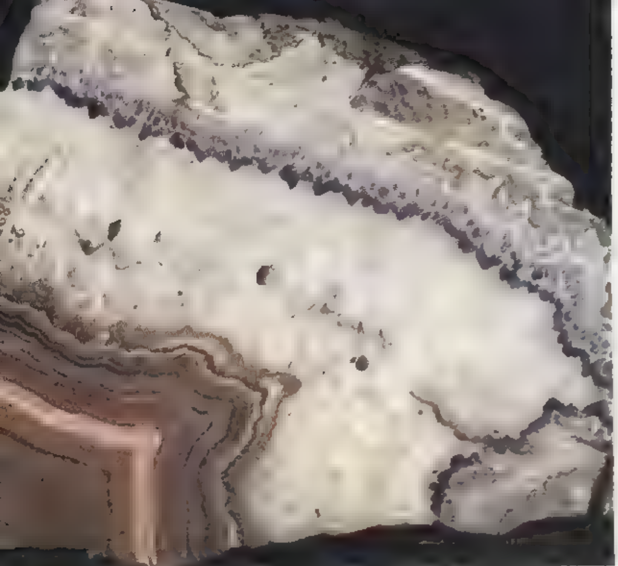
Minerals and other true solids, natural or synthetic, tend to form crystals. Crystals are symmetrical masses with definite angular geometric shapes. We now know that the outer angular faces of a crystal are related to the atomic structure within it. The atoms or ions (electrically charged atoms) of the crystal are arranged in definite positions relative to each other, forming a basic pattern known as a *lattice*. This was definitely proved in the year 1912, when the German physicist Max von Laue used X rays for the study of crystals. X rays have proved the existence of the crystal lattice beyond a doubt, and they have thrown much light on crystalline structure. When the rays are passed through a crystal, they are scattered, or diffracted, by the atomic planes, or layers, inside the crystal. A "shadow" image of the planes is projected onto photographic film and developed. The crystal structure can then be derived from the analysis of the shadow pattern. The British physicists Sir William H. Bragg and Sir William L. Bragg (who were father and son) made important researches in the field of crystalline structure.

Long before the true nature of crystals had been revealed by X rays, they had been

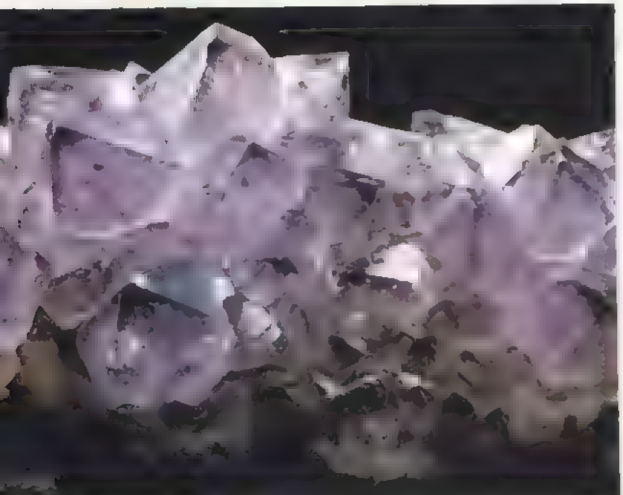


J. Six



J. Six

Left top: a specimen of banded agate, surrounded by layers of quartz and amethyst. Banded agate is a form of multicolored chalcedony. Bottom: amethyst, a clear purple or blue-violet variety of quartz. It is often seen lining the inner wall of hollow rock. This mineral is also a gemstone and is quite popular for jewelry.

In the Mohs scale, certain standard minerals are given a hardness rating from one to ten, as follows:

1. Talc	4. Fluorite	8. Topaz
2. Gypsum	5. Apatite	9. Corundum
3. Calcite	6. Feldspar	10. Diamond
	7. Quartz	

Talc is the softest of these minerals; diamond, the hardest. A given mineral in this scale can scratch any mineral with a lower number; it can be scratched by any mineral with a higher number. To determine the hardness of a mineral not represented in the scale, we try to scratch the mineral with one of the standard minerals listed above. We start with the softest one and then advance up the scale. If the unknown mineral can scratch calcite but is scratched by fluorite, its hardness is given as $3\frac{1}{2}$. If it seems closer to calcite in hardness than to fluorite, it might be given $3\frac{1}{4}$.

It is possible to determine the hardness of minerals more exactly than would be possible with the Mohs scale. Most mineralogists feel, however, that the measurements that are made with the Mohs scale are quite accurate enough for practical purposes.

Color. Color may also help identify various minerals. It is not always a reliable guide, however, because of its changeable nature. Impurities in a mineral specimen often determine its particular hue. Certain minerals, however, have striking and characteristic colors and have been used in making paints. Copper carbonate, or malachite, for example, is a lovely green. Lapis lazuli, or lazurite, is ultramarine.

Streak. The streak of a mineral is related to both color and hardness. A mineral softer, say, than white porcelain tile (hardness 7) may leave a colored streak on the latter if scraped across it. Strange to say, the color of the streak is often more constant and a more certain means of identification than the color of the mineral producing the streak. For example, specimens of hematite and limonite, both different iron oxides, may have the same external color—black. However, the hematite may be distinguished from the limonite by its red streak. The streak of limonite is yellow-brown or rusty.

Luster. The property called luster, or sheen, is often useful in identifying minerals. A mineral may have a metallic, greasy, glassy, resinous, silky, pearly, or adamantine (diamondlike) luster. This property is closely related to a crystal's internal structure and habit, which affect the way it reflects or transmits light. Some minerals

have no real luster at all, but may form dull, earthy masses.

Density. Density is another distinguishing characteristic of minerals. The density, or weight per unit volume, of a substance depends on the weight of the elements of which it consists and on how closely they are packed in the crystal structure. Density is often given in terms of specific gravity—that is, in terms of the ratio of the weight of a substance in air to the weight of an equal volume of water. The specific gravity of the diamond is 3.5, while that of graphite is 2.3. This may seem surprising, since they both consist of carbon. However, they differ in crystal structure.

Often, apparently similar minerals, such as dark cassiterite and black tourmaline, can be easily distinguished because of significant differences in specific gravity, that of cassiterite being much greater. Once we have acquired experience, we can distinguish even minor weight differences between equal volumes by lifting them.

Cleavage. Cleavage, or splitting, is determined by the atomic arrangement in a crystal. If the atoms in a crystal are densely packed or strongly united, cleavage is difficult. It is easy wherever the atoms are widely spaced or weakly bonded. A mineral may split along what is called a *cleavage plane,* which is often parallel to a crystal face or a possible crystal face. There may be several cleavage directions in a single mineral. In some of these directions cleavage may be easier than in others. A cubic crystal of fluorite has octahedral cleavage; this means that all of the cube corners can be broken off completely, resulting in an octahedron, or eight-sided solid, resembling two four-sided pyramids placed base to base. Since cleavage is related to the crystalline structure, it is useful as an identifying property of crystals.

Parting. The property of parting involves splitting in a certain plane. However, parting is not quite the same thing as cleavage, since it is due not to the normal arrangement of atoms, but to chance weaknesses that may develop in a mineral mass for any number of chemical or physical reasons.

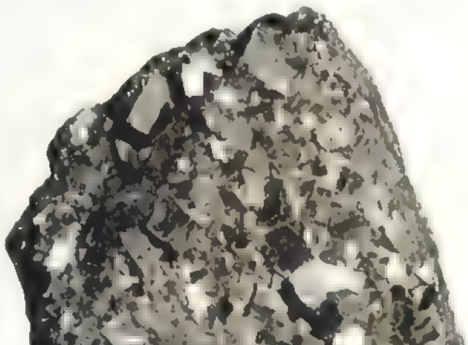
Fracture. Fracture, or breaking off, is not related to any plane or internal direction. However, minerals do have a tendency to break apart in a certain way. Some minerals, especially native metals, have a jagged fracture. Quartz, like glass, gives a conchoidal break—that is, the fracture exhibits a shell-like, curved surface. (The Latin *concha,* derived from the Greek word *konche,* means "shell.")

Tenacity. Tenacity represents the resistance of a mineral to breaking under force or strain. A brittle mineral, such as quartz, has little tensile strength and will shatter from a heavy blow. On the other hand, gold and copper can be beaten into sheets; copper and silver can be drawn into wire.

BEHAVIOR OF MINERALS

The behavior of minerals—the internal forces they possess and the way minerals react to external forces or forms of energy—often provides a clue to their identity. Among the internal energies that distinguish one mineral from another are magnetism and radioactivity. Certain minerals, such as the iron compounds magnetite and pyrrhotite, are magnetic. This property was known to the ancients. The magnetic qualities of magnetite, or loadstone, were mentioned by the Greek philosopher Thales, who lived in the seventh and sixth centuries B.C. The property of radioactivity, asso-

Pyrite, or "fool's gold," is an iron sulfide. It has massive cubic crystals, a brassy-yellow color, and a metallic luster. It is often confused with gold.



C Nundsony

COLLECTING MINERALS AND ROCKS

ually. No specimen should be allowed to rub against another. Both may be ruined as a result. Do not start wrapping your specimens too soon. Wrap toward the end of the day, picking out only the best. If you go to more than one locality in a day, or if you don't expect to unwrap the specimens as soon as you get home, write on the outside of the paper with a crayon where you got each piece so that later you will be able to make out a proper label. Do not take pieces that are too big. There is a limit to the number of large specimens that you can keep in your collection.

IDENTIFYING MINERALS

The next step is to identify the specimens. For this purpose, you should use a field guide to the minerals. There are about two thousand known minerals. It would be quite impossible for an amateur to identify every one of them. Limit yourself to the commoner minerals—about 250 or so in number. It is possible to identify minerals by comparing their properties with those listed in a field guide or textbook. Here are some sample tests for determining properties.

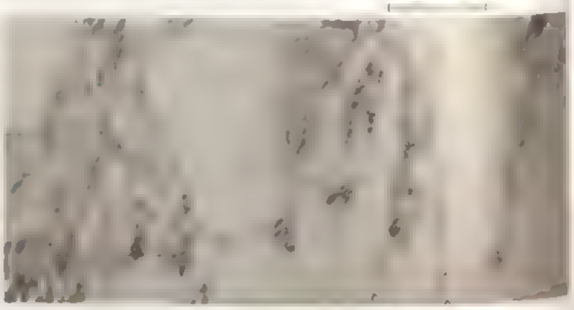
We test the hardness of a mineral by taking pieces of test minerals of known hardness and using them to see if our specimen is harder or softer than they are. These test minerals form a series that is known as the *scale of hardness*, or the *Mohs scale*. Talc is the softest mineral known: it is 1 on the scale. Diamond is the hardest mineral: it is 10. The other minerals are assigned numbers between 1 and 10. See the article "Minerals" in *The New Book of Popular Science*.

To apply the scale, we try to scratch the specimen with one of the test minerals. If no scratch appears on the specimen, it means that it is harder than the test mineral. Start with the softest test mineral in making this test. If you start with the hardest, you may mar the specimen by making half a dozen scratches across it before you determine its hardness. On the other hand, if you start with talc and work your way up the test minerals of the scale, a single scratch will tell the story.

If an unknown specimen is hard[illegible] than fluorite (4 on the scale) and yet [illegible] be scratched by the next test mineral [illegible]ve it in the list, we say its hardness is 4[illegible] If it seems closer to apatite, (5 on th[illegible]ale) than to fluorite, we might give the h[illegible]ess as 4¾. After you succeed in scratc[illegible] the specimen, wipe off the mark with y[illegible] finger and look again. The specimen [illegible] not really have been scratched at all. T[illegible]mark may have been something that rub[illegible] off from the test mineral.

If you are still not sure about t[illegible]ntity of a mineral after applying all th[illegible]ove tests, you may have to do a little c[illegible]al laboratory work. The chemical mo[illegible]ten employed by collectors is hydr[illegible]ric acid. We use it, for example, to help [illegible]decide whether a certain specimen is t[illegible]ry common mineral calcite. Calcite is [illegible]um carbonate ($CaCO_3$). Marble, commo[illegible]estone, and chalk are all forms of t[illegible]ubstance. If we put a drop of hydro[illegible]ric acid on calcite, bubbles will form as pa[illegible] of the calcite is dissolved and the [illegible]on dioxide gas in the mineral escapes [illegible] the acid is in a test tube, a grain of calcit[illegible]ay

Marble is a metamorphic rock. It is limesto[illegible]at has been crystallized by deformation. Top[illegible]le marble. Bottom: black marble. Right: a quar[illegible]



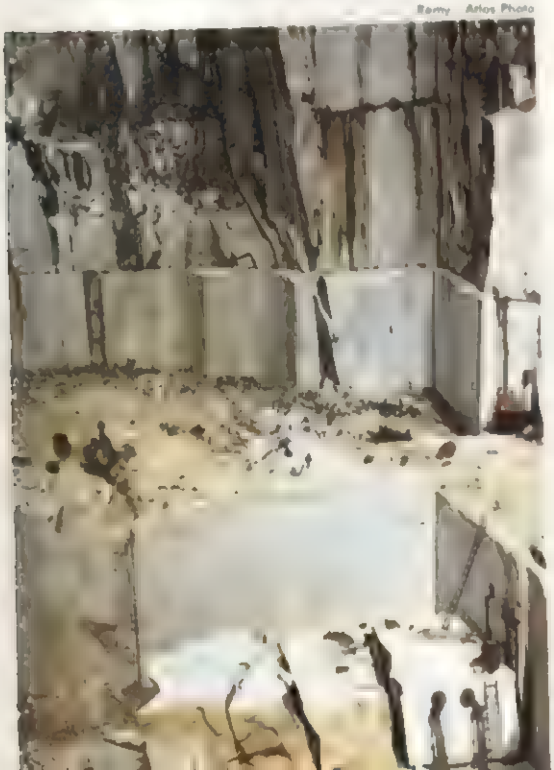
be put in the tube and bubbles will form. Other acids, such as acetic acid, found in white vinegar, also make calcite bubble.

In another type of test, we set up a miniature version of a smelter. Smelting consists of roasting ores in order to separate desired metals from the chemical elements with which they are combined. For example, metalic elements, such as copper, lead, and zinc, are often combined in a natural state with sulfur, making up the chemical compounds known as sulfides. Many of them have only to be roasted in the hot flame of a smelter in order to burn off the sulfur, leaving the metal.

The mineral collector can have a private smelter, consisting of a blowpipe and a piece of charcoal, in which a small pit has been dug. Put a small grain of the metallic mineral that you think may be a metal ore into the pit. Then supply heat with a candle or alcohol flame. Using the blowpipe, direct a flame down into the charcoal pit. If the specimen is a sulfide, sulfur fumes will come off. Eventually there will be a little ball of red-hot metal swirling around in the charcoal pit like a lively bead.

When the metal ball or button has cooled, you can flatten it out with a hammer and see if it looks like lead or silver or copper. If you can identify the metal, you will know two of the elements in the unknown metallic mineral—namely sulfur and the metal.

Betty Atlas Photo



RECORD YOUR SPECIMENS

After you have identified your mineral specimen, you should label it and perhaps enter it in a catalog. The label should have the name of the mineral and the locality where it was collected. It might also be helpful to add the date. Many people also paint a number on the specimen and keep a card file in which they put additional information that is of interest, such as crystal shape or the other minerals associated with it in the specimen. A much better way of numbering your specimens is to use the specimen numbers employed in a standard textbook and to add a consecutive number of your own. Whatever system you use, be sure to keep some kind of report of your specimens. An accumulation of minerals without any labels is almost valueless to anyone but the collector himself and even to him its value is limited.

GEMSTONES

Among the many varieties of minerals found in the earth, some are particularly prized because they are rare, or durable, or beautiful, or because they combine these qualities. Such minerals were formerly divided into two principal classes. Those which were particularly outstanding, such as diamonds, emeralds, and rubies, were known as *precious stones*. Other minerals that were not so rare and not so beautiful were called *semiprecious stones;* these included moonstones, zircons, and agate. This distinction is still sometimes made. Generally, however, any mineral that possesses marked qualities of beauty and durability and that may be used for personal adornment after having been processed is called a *gem*, or gemstone. Some collectors of minerals make a hobby of cutting and polishing various gemstones that they find in the field. The art of polishing gems is called *lapidary*. The person who processes minerals in this way is called a lapidary or a *lapidarian*.

Fundamental Photographs

Sulfur-bearing rock from Sicily.

ROCKS

By the time that you have acquired a nodding acquaintance with some of the more important minerals, you may want to start a collection of rocks. Before doing so, you should have some idea of the different kinds of rocks of which the earth's crust consists.

There are three main kinds of rocks: igneous, sedimentary, and metamorphic. Igneous rocks were formed by the solidifying of molten rock-producing matter. Some of this matter flowed from a volcano and cooled very quickly. The individual mineral grains did not have much chance to grow. The igneous rock that resulted is fine-grained and compact. If the molten rock remained below the earth's surface until it solidified, it cooled slowly. The crystals had a long time to form and grew quite large. The result is a coarse-grained igneous rock, such as granite. Such rocks have generally been exposed either by the uplifting of the crust or the erosion of overlying rocks.

Sedimentary rocks consist of sediments that have been transformed into rocks in the course of the centuries. Sedimentary rocks are derived not only from rock fragments but also from plant and animal remains. In some instances, they have been built up through the evaporation of ocean water. The sedimentary layers of the earth's crust make up most of its surface area. In some places, the accumulations of layers may be many hundreds of meters thick.

Metamorphic rocks are former igneous or sedimentary rocks that have been transformed within the earth's crust into quite different kinds of rocks. This transformation has been due to various factors, such as pressure, extremely high temperatures, and the presence of water. The original rock particles have been forced into new arrangements. Sometimes new minerals have been formed.

Here is a brief summary of some of the important rock formations you may find in the course of your collecting.

Igneous rocks: evenly grained, usually without pronounced layering or banding, made of the silicate minerals and, therefore, relatively hard and compact. Among the fine-grained igneous rocks are: (1) Basalt: a dark rock (black, brown, dark green, or dark grey) of volcanic origin. (2) Porphyries: rocks with large crystals set in a mass of finer-grained ones, called the groundmass. (3) Rhyolites: comparatively light-colored rocks, ranging in color from white to gray, pinkish red, and purple.

Among coarse-grained igneous rocks are: (1) Granites: composed mainly of quartz and feldspar and, generally, of mica also. (2) Diorites: composed of feldspar and one or more dark minerals. The feldspar predominates. (3) Gabbros: composed of feldspar and one or more dark minerals. The dark minerals predominate. (4) Peridotites: generally black or dark. They contain large amounts of iron. (5) Pegmatites: particularly coarse-grained granites, containing large crystals of quartz, feldspar, and mica.

Sedimentary rocks: made up of more or less rounded mineral fragments. Sedimentary rocks usually show bedding—if not in the collected specimen, then certainly in the quarry or the road cut where they are to be found.

There are five types of sedimentary rocks: (1) Conglomerate: pebbles or larger rock fragments cemented together. (2) Sandstone: sand grains cemented together. (3) Shale: clay that has been converted into layered rock masses. (4) Limestone: made up of microscopic shells or precipitated calcium carbonate or both. Many lime-

stones have clay and sand mixed with them. (5) Gypsum, common salt, Glauber's salt, and Epsom salts: compounds contained in seawater that precipitated as the water evaporated.

Metamorphic rocks: contain some of the same minerals as those of granite, but these are in different proportions. Metamorphic rocks may consist of only one kind of mineral and not a mixture of several as in many igneous rocks.

The metamorphic rocks are: (1) Gneiss: looks a great deal like granite but has alternating layers of different minerals, giving it a streaky appearance. Most varieties contain black mica. (2) Schist: much the same as gneiss, but the commonest mineral may be mica. It can be broken up into sheets. (3) Quartzite: does not look very different from the sandstone from which it is formed. It is cemented together a little more firmly. When a piece is broken, the sand grains break across, instead of around, the grains, as is the case in sandstone. Quartzite is one of the hardest and most resistant rocks. An outcrop (exposed surface) of a quartzite bed is likely to take the form of a cliff. (4) Marble: made by the recrystallization of limestone. It may be fine or fairly coarse, and it may be almost any color. Since it is calcite, it can be scratched by a knife. It bubbles in acid. (5) Slate: so fine-grained that the separate mineral grains cannot be readily distinguished. It splits into smooth slabs.It is mostly blue-black, but there are also black, green, and red varieties.

FOSSILS

Rock collectors can sometimes find fossils in sedimentary formations, particularly in limestones and shales. There are several kinds of fossils. The commonest are the shells of various animals. You are most likely to find them in slightly shaly limestone beds, especially where these are exposed on weathered slopes. The fossils are often shells that have been replaced by calcite or even quartz. Shell fossils may stand out on a slope or may even be perched on pedestals like golf balls on tees.

Leaf fossils are found as impressions between two layers of shale. You must split the sheets apart to find the fossils. One of the best places to look for leaf fossils is in the shales that overlie coal beds.

Land animals have left fossil remains, too. Since land animals did not develop until late in earth history, the number and variety of their fossils cannot compare with those of sea animals.

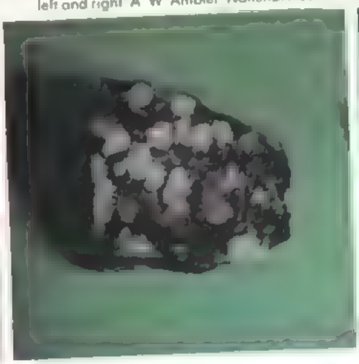
COLLECTOR'S GUIDES

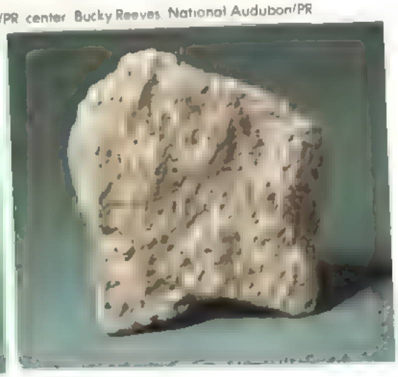
After you have become an experienced collector of rocks and minerals, you will find it rewarding to subscribe to magazines dealing with your hobby. You will also want to find out about mineral dealers and collector's clubs.

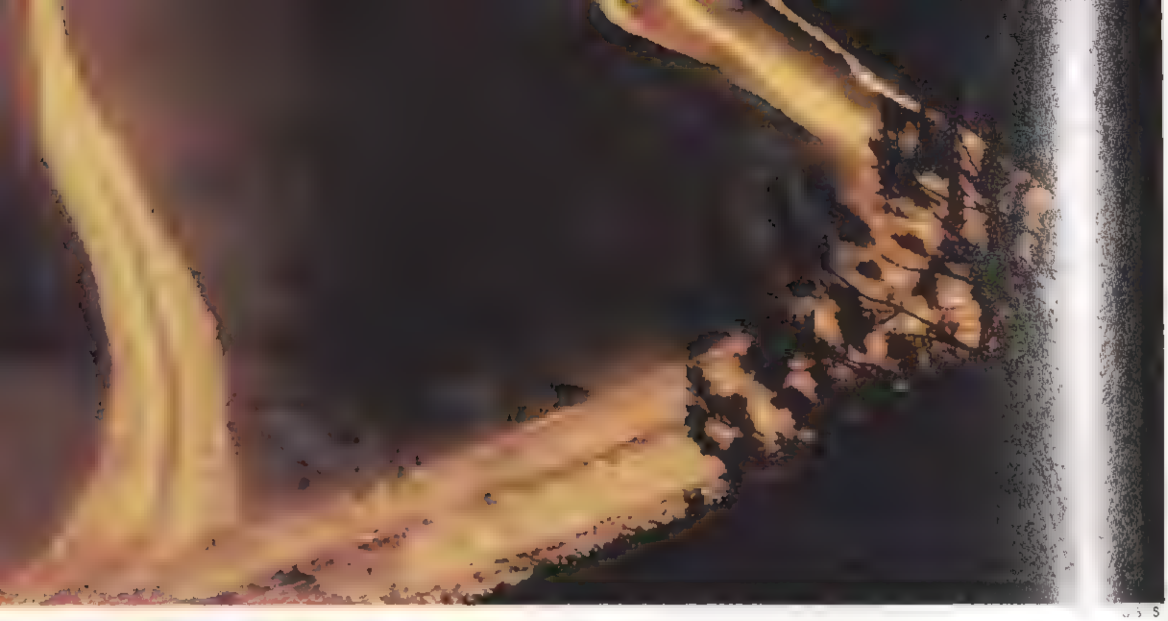
Collect what you can, but do not hesitate to fill in any gaps in your collection by having recourse to dealers. This is cheaper than going far afield in order to seek missing specimens.

Lavas are examples of igneous rocks. Left to right: basalt, obsidian, scoria.

left and right A W Ambler National Audubon/PR center Bucky Reeves National Audubon/PR







Volcanism is one of the most dramatic manifestations of the powerf[illegible]es at work deep within the interior of the earth.

THE INTERIOR OF THE EARTH

by Keith E. Bullen

People have come to know a great deal about the surface of the earth through direct or fairly direct observation. They have explored it, surveyed it, and mapped it from the air, and they have analyzed its rocks. One could not apply such methods to the study of the earth's interior. The deepest mines penetrate less than three kilometers. The deepest boreholes do not go down much farther. These are the merest pinpricks in a planet the size of earth.

Indirect means must be used, therefore, to learn about the internal structure of the earth. The geophysicist, or earth scientist, gathers evidence from various sources. The geophysicist analyzes data bearing on earthquakes and the rotation of the earth, measures the tides, and considers variations in gravity at various parts of the earth's surface. The geophysicist also tries to reproduce in the laboratory the conditions that are believed to exist in the interior of our planet.

Because of the indirect nature of the evidence with which he works, the earth scientist is cautious in most statements and likely to use the word "probably" a great deal. Yet we must not forget that there is a great deal of "probability thinking" in any kind of scientific investigation. All human judgments are uncertain, to some extent at least, even when they are based on eyewitness evidence. As a matter of fact, the scientific instruments that the geophysicist uses are often more reliable than the human eye.

Some conclusions can be safely accepted. It is just as probable, for example, that a dense core exists in the earth as it is that the sun will rise tomorrow. In other cases the earth scientist's findings are tentative. Theories may have to be modified as new data are acquired.

EARTHQUAKES GIVE CLUES

The earth itself provides the principal

means by which we can solve the mystery f its internal structure. Every year a num- er of earthquakes occur in many different arts of the globe. Each earthquake releas- s suddenly a tremendous amount of ener- . This energy travels from the *focus*, or urce, of the disturbance in the form of ves through all parts of the earth, includ- g the very deepest parts. When the waves nerge at the surface, they are recorded by truments called *seismographs*. Seismo- raphs are located in several thousand ob- vatories spread widely over the globe.

The seismograph needle traces the vements of the earth under our feet on rds called *seismograms*. An earthquake rs, say, in New Zealand. Some twenty nutes later an observer in England can ch the seismograph needle trace the pat- of the arriving waves.

Some twentieth century seismologists prepared accurate tables, giving the s of travel of earthquake waves ugh all parts of the earth. The Jeffreys- n tables are now used internationally. y were prepared by Sir Harold Jeffreys, Cambridge University, with the help of ith E. Bullen, during the period 1931– 40. Other useful tables have been com- ed by B. Gutenberg and C. F. Richter of California Institute of Technology.

Two types of waves penetrate deep in e earth – P waves (primary waves) and S waves (secondary waves). P waves travel through both solid and fluid parts of the earth's interior. In the rocks near the surface they move at about 5 kilometers a second. They reach their maximum speed of 14 kilometers a second at a depth near 2,800 kilometers. S waves travel at about two-thirds the speed of P waves in solid regions. They do not travel at all through fluid regions.

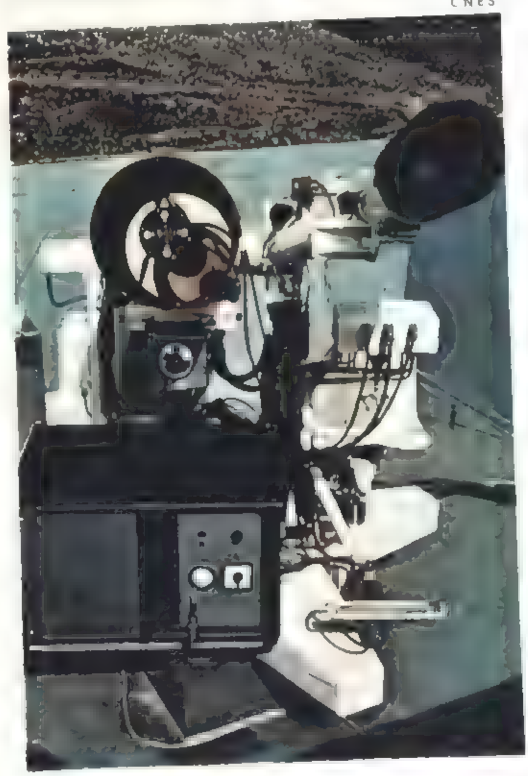
When the waves reach a boundary between layers of the earth, they may be reflected, passing upward toward the surface. They may be refracted, or bent, as they pass on to the next layer, as well as reflected. This means that they penetrate this layer, changing their direction. The waves that reach the earth's crust are reflected downward again.

The speed of the P and S waves varies according to the depth of the parts of the earth through which they travel. The seismologist can calculate all these variations. He then charts the interior of the earth, dividing it into regions on the basis of depth.

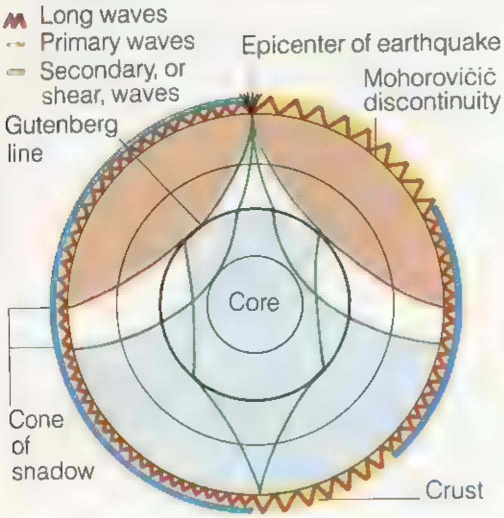
Seismograms can be compared to X rays of the human body. The internal structure of the body influences the intensity of the X rays as they pass between their source and the photographic film or plate. As for the nether regions of the earth, they affect the earthquake waves traveling between the source of an earthquake and the seismograph. It is much more difficult to interpret seismograms than X-ray photographs. As a physician examines an X-ray photograph, he sees a picture bearing a definite resemblance to the human body. A seismogram, however, offers only an intri-

Geologists have developed many delicate instruments to study the earth. From the data collected by such devices, they can piece together ideas concerning the earth's interior. This photo shows a device used to study the earth's magnetism.

CNES



PROPAGATION OF SEISMIC WAVES

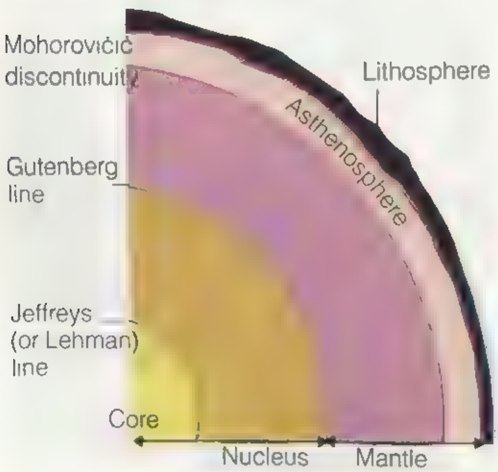


cate pattern of wavy lines. To decipher these, an earth scientist needs to employ the methods of mathematics and physics.

TWO INTERIOR REGIONS

The evidence obtained from seismograms indicates that the interior of the earth is divided into two main regions; a central *core,* and a *mantle* surrounding this core. The crust and upper part of the mantle is known as the *lithosphere*. It is a layer of rigid rocks.

INTERIOR OF THE EARTH



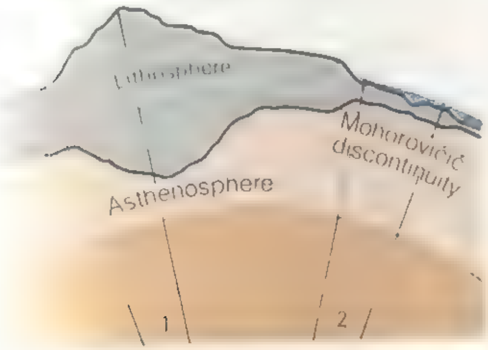
In 1914, the German-American geophysicist B. Gutenberg calculated, from an analysis of earthquake-wave velocities, that the earth's mantle is about 2,800 kilometers thick. This level, known as the *Gutenberg line,* is the boundary between the mantle and the core. Both P waves and S waves are transmitted everywhere in this region. Since S waves do not pass through fluid matter, the mantle must be essentially solid throughout, except for the oceans and limited pockets of volcanic matter.

A. Mohorovičić made a significant discovery in 1909 as he analyzed the seismograms of a Balkan earthquake. He found that there was a marked change in the earthquake-wave velocities after they penetrated some tens of kilometers below the earth's surface. The P and S waves traveled at slower and more variable speeds before they reached this level than they did afterward. The level corresponds to a more or less sharp boundary. This is known as the *Mohorovičić discontinuity.*

Later it was discovered that this boundary extends all over the world. It is generally found about 35 kilometers below the surface of the earth in continental areas. The depth is somewhat greater below mountain ranges. It is only about eight kilometers below the main ocean floors. The part of the mantle beneath the lithosphere and above the Mohorovičić discontinuity is known as the *asthenosphere*. It is softer and more easily deformed than the uppermost layer. The mantle is again rigid beneath the asthenosphere.

The core of the earth consists of three regions; an *inner core, outer core,* and a *transitional layer* of 480 kilometers in between. S waves cannot penetrate liquid matter. The fact that they do not enter the outer core makes it likely that this is in a liquid state—a conclusion that is well established from certain other lines of evidence. P waves pass into the core. As they do so, their velocity drops suddenly from 13.5 kilometers a second to 8 kilometers a second, and they are refracted sharply. This refraction causes a great reduction in the intensity of waves penetrating to the surface in an area called the shadow zone. It was the

PRINCIPLE OF ISOSTASY



...egions of the earth's crust are in a state of ...librium, known as *isostasy*. If the earth's ...r layers were divided into two columns – one ...mountainous area, the other under the sea – ...columns would have the same weight. Differences in the weight of the lithosphere would ...ompensated for by the deformable as...sphere.

...ence of this zone that first provided ...ophysicists with proof that a central core ...ally exists. There is a marked increase in ...e velocity of the P waves when they ...ch the inner core. There is strong evi...ce that this part of the core is solid.

The inner core has a radius of about 1,300 kilometers. The thickness of the outer core is greater than 1,600 kilometers. Thus the combined inner and outer core, with the transitional layer, has a radius of about 3,500 kilometers or a little less.

The interior of the earth has been tentatively divided into several other regions. In particular, there are signs of some fairly marked changes in the earth's rocks below the crust.

DENSITIES AND PRESSURES

We can find the density of any body if we know its mass and its volume, since density is the mass per unit of volume. The earth's mass is known to be nearly 6×10^{21} metric tons. Its volume is about 1.1×10^{12} cubic kilometers. Using these data, scientists have calculated that the earth as a whole has a density of $5.517 \pm .001$ grams per cubic centimeter. Water has a density of 1 gram per cubic centimeter at ordinary temperatures. This means that the earth is about 5.517 times as dense as water. The density of a substance compared with that of water is called its *specific gravity.* The figure 5.517, therefore, represents the average specific gravity of the earth.

Most rocks at the earth's surface have specific gravities of less than 3. Of course, since the specific gravity for the earth as a whole is more than 5, the earth's interior must contain denser material than the surface rock. By studying earthquake-wave patterns, earth scientists can calculate the densities in the different parts of the mantle and core. The reason is that the wave velocities in a region depend on the density of the materials through which they pass.

Other kinds of evidence are also needed in estimating densities at various points below the earth's surface. One source of information is based on the earth's spin. We

In an attempt to learn how the earth's interior is affecting the crust scientists have taken "cores" of the ocean floor using equipment such as this "super straw."

Woods Hole Oceanographic Institution

Keystone

The earth as the 15th century represented it. We have learned much since then, but still have many unanswered questions, particularly about the nature of the earth's core.

know that, roughly speaking, the earth rotates about an axis passing through the two poles. We know, likewise, that partly as a result of this rotation, our planet bulges somewhat at the equator. The gravitational attraction of the moon on the bulge at the equator brings about certain small changes in the direction of the axis. These have been detected and measured by astronomers. The geophysicist considers these changes in relation to certain known facts concerning the shape of our planet. Various physical theories of elasticity and gravitational attraction also help determine the densities. So do laboratory experiments on rocks.

Through all these means, Keith E. Bullen calculated in 1936 that the density of the earth, expressed in terms of its specific gravity, ranges from a little over 3 just below the crust to about 5.5 at the base of the mantle. The increase of density with depth is brought about mainly by the tremendous pressure exerted by the overlying rocks. It may also be due in part to changes in the chemical composition of the mantle.

At the boundary between the mantle and the core, the specific gravity jumps suddenly from 5.5 to nearly 10. Inside the outer core it increases, because of the greater pressure, until it reaches 11.5 at the bottom. These figures are widely accepted at the present time.

The density of the inner core has been calculated precisely. Dr. Bullen estimated that the specific gravity of the earth at its center is about 13.

Once we know the density variation within the earth, we can calculate the pressure distribution. The atmospheric pressure is about 1 kilogram per square centimeter at sea level. At the floor of the Pacific Ocean the pressure is somewhat less than one metric ton per square centimeter. This impressive figure is insignificant when compared with the pressure in the very deep interior. Dr. Bullen has estimated that the pressure at the bottom of the mantle is about 1,550 metric tons per square centimeter. It is about 3,900 metric tons per square centimeter at the earth's center. It would take a column of steel about 800 kilometers high resting upon a square centimeter of surface to produce a force of 3,900 metric tons.

ELASTICITY OF THE EARTH

The earth is not an absolutely rigid body, but yields elastically under stress just as steel does. For this reason the attraction of the sun and moon causes tidal movements to arise not only in the oceans but in the solid earth as well. Certain fluctuations in the position of the earth's axis are also due to the elasticity of our planet.

The *rigidity* of a body is its resistance to forces that tend to distort shape. In 1863, Lord Kelvin calculated, on the basis of these effects, that the average rigidity of the earth is rather greater than that of steel. This means that, considered as a whole, our planet is much more rigid than the average

surface rock. Since Kelvin's time, knowledge of the earth's density variations has made it possible to calculate the rigidity and seismic velocities in the earth's interior. The rigidity increases throughout the mantle. Dr. K. E. Bullen estimates that it is about three times that of ordinary steel at the mantle bottom.

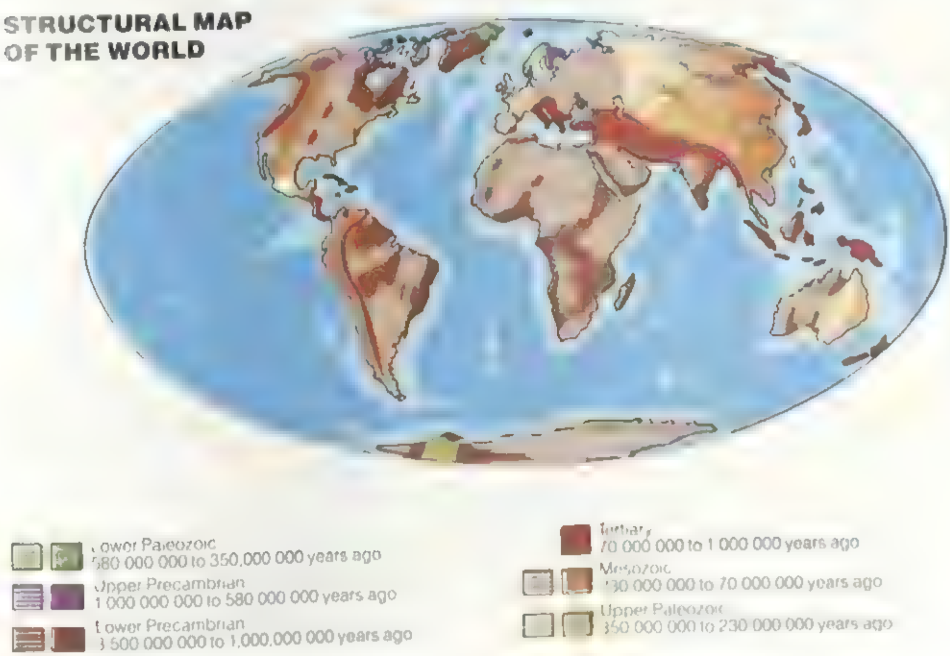
The Japanese scientist H. Takeuchi used earthquake data and data on the tidal motion of the solid earth to show that the greater part of the outer core is far less rigid than the mantle. This finding gives the strongest support to the theory that the outer core is in a molten state. An independent series of calculations by Dr. Bullen makes it highly probable that the inner core is solid. This part of the central core has a rigidity comparable with that of ordinary steel.

TEMPERATURE AND HEAT OUTFLOW

We have no precise evidence bearing on the earth's internal temperature. The temperature at the bottom of the crust is probably about 500°–1,000° Celsius. It rises steadily with increasing depth. The fact that the earth's mantle is not molten sets an upper limit to the possible temperature at its bottom. Estimates range from 2,000° Celsius to around 6,000° Celsius. The temperature at the center of the earth is likely to be less than 1,000° Celsius greater than these figures.

There is a small but steady outflow of heat from the earth. By far the greater part of this heat comes from radioactive material in rocks near the surface. In continental regions the radioactivity is mainly in granitic rocks in the crust. Such rocks are absent in most oceanic regions. It was assumed, therefore, until recently that the heat flow through the ocean floors would be much less than that from the continents. Later measurements, however, seem to indicate that the heat outflow from the earth is fairly uniform over the entire surface. Fluctuations do not exceed 20 per cent.

...urface of the earth has changed and is continuing to change. Many of ... changes occur as a result of powerful forces within the earth's interior. The map shows changes through geologic time.



COMPOSITION

It is generally believed that the material immediately below the crust consists of silicate rock. Silicates are rocks containing one or more elements combined with silicon and oxygen. It is not certain what the predominant rock is in this region. It is thought likely, however, that the mineral olivine, which is an iron-magnesium silicate, may be found here in quantity. The evidence for this comes by matching earthquake wave velocities for this region against certain experiments made on rock in geophysical laboratories.

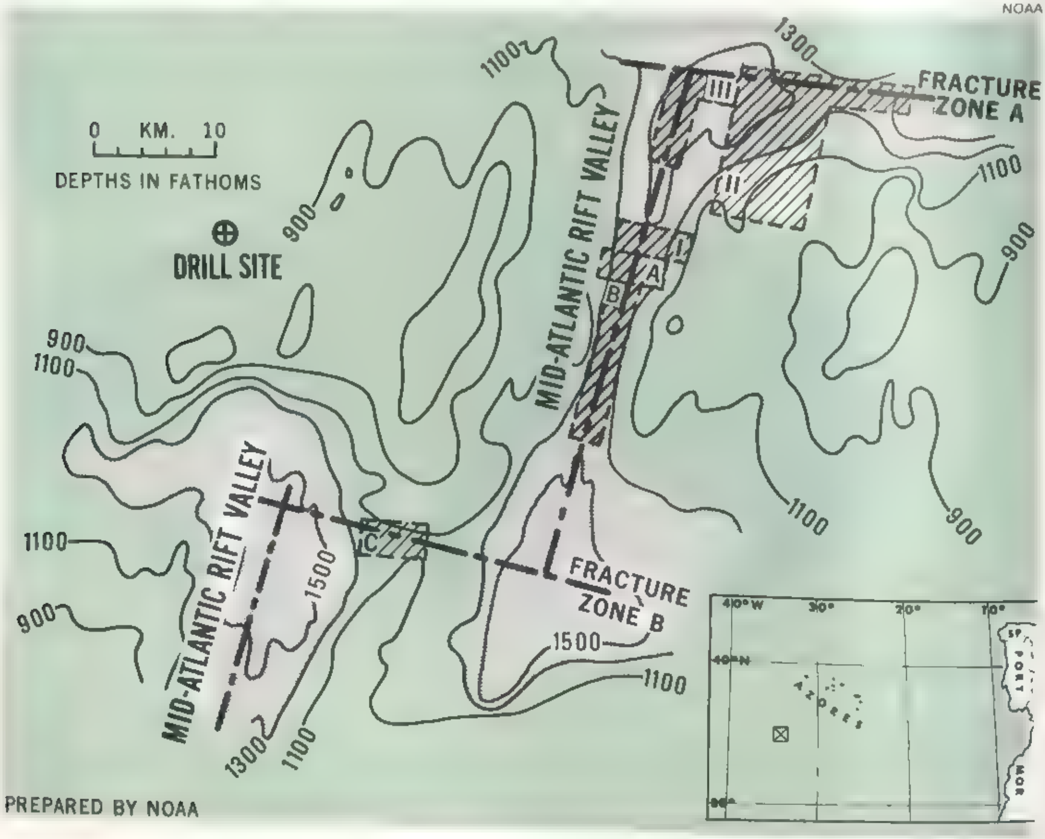
In the lower part of the mantle, the composition of the rocks appears to be much the same as higher up. It is possible, however, that the material in this part of the mantle may consist of distinct silica, magnesia, and iron oxide phases. This has been suggested by Francis Birch of Harvard University.

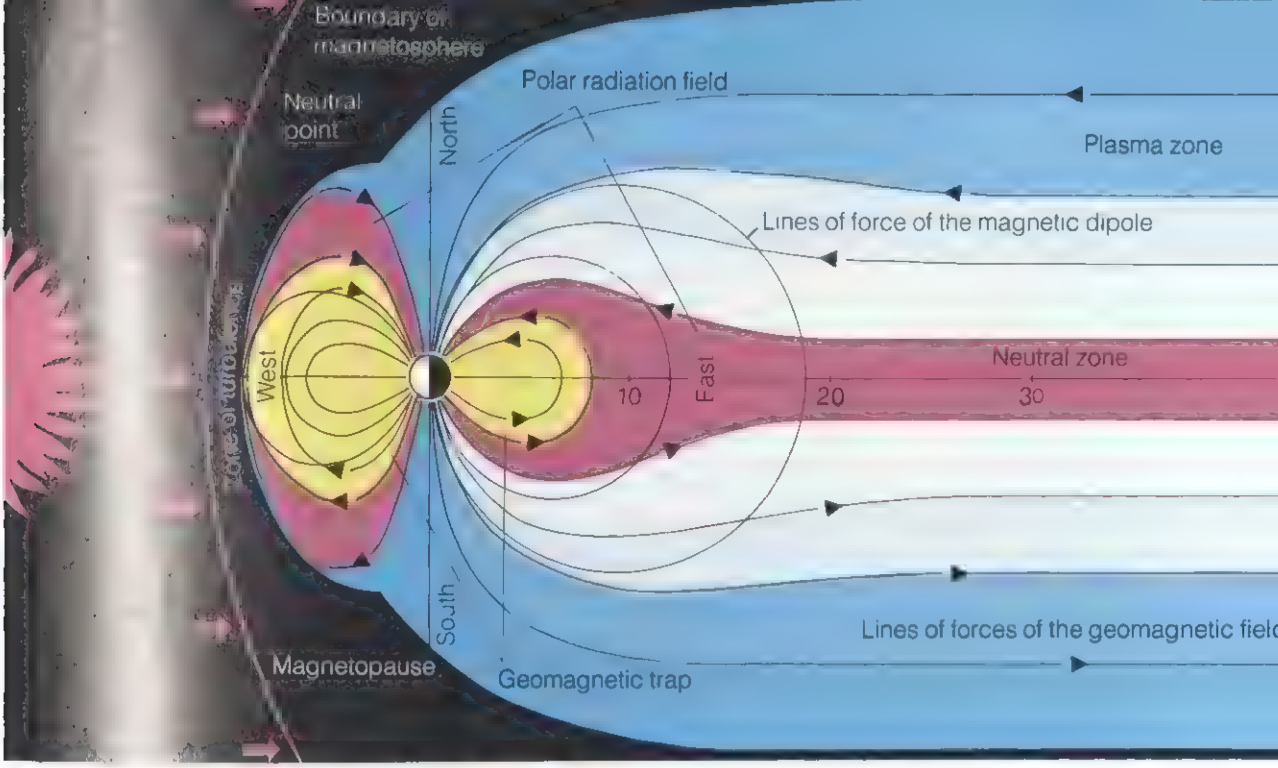
Until quite recently it was almost universally believed that the central core of the earth was made up chiefly of nickel-iron. This idea was based to a large extent on the study of meteorites, fragments that have fallen to the earth's surface from outer space. Meteorites fall into three main classes. There are "irons," consisting of iron often mixed with nickel; "stones," resembling rocks at the earth's surface; and "stony irons," a mixture of the first two types.

It is generally agreed today that meteorites are fragments of much larger bodies. An analysis of the "irons" indicates that the

The Mid-Atlantic Ridge has been the site of some of the most exciting studies of what is now happening to the earth. It is believed to be a site where the action of the earth's interior in forming the crust can be observed and measured.

NOAA





The earth is surrounded by a vast envelope known as the magnetosphere The solar wind – the constant stream of particles emitted by the sun – shapes this envelope as the above illustration shows.

crystals they contain were formed through the slow cooling of solid nickel-iron. This cooling took place at pressures occurring only deep down in bodies of considerable size. It has been calculated that the "irons" were formed inside a body perhaps as large as the moon.

This suggests that at least some meteorites have come from a planet that was once like the earth but that has been broken up into fragments. The fragments of such a body would be like the materials deep in the earth. If, as was once believed, most meteorites are "irons," nickel-iron must predominate in the earth's core.

Today we realize that the proportion of "irons" to "stones" is not nearly so great as it was once thought to be. A recent survey by J. Öpik put the proportion as low as two per cent by mass. Other investigators put the "iron" percentage higher than Öpik. However, the matter is far from settled. Whether we accept Öpik's figure or a higher figure than his, it is clear that evidence provided by meteorites for the nickel-iron content of the central core is not so conclusive as it formerly seemed.

Most geophysicists still believe that the inner core of the earth is made up of nickel-iron, with perhaps some slightly denser materials as well. Many hold also that the outer core also consists chiefly of nickel-iron – not solid, but in molten form. Others have their doubts. In 1948 the British scientist W. H. Ramsey advanced the idea that the outer core has the same chemical composition as the lowest part of the mantle. The difference in density between the two regions, he held, is due to the increased pressures below the mantle. This theory needs much more testing before it can be regarded as supplanting the older theory to which we referred above. However, it has influenced the thinking of a number of earth scientists.

THE EARTH'S MAGNETIC FIELD

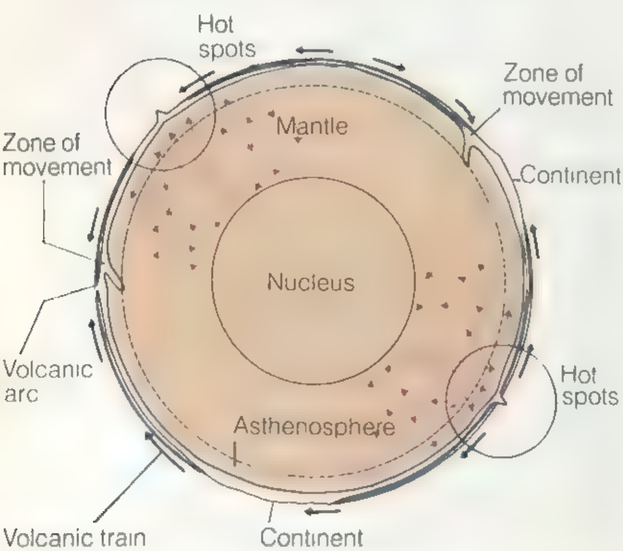
In the year 1600 Sir William Gilbert,

an English physician, set forth the theory that the earth has the properties of a huge magnet, whose magnetic poles nearly coincide with the geographical poles. He also suggested that the earth's magnetic field originates mostly in the deep interior. These ideas have been confirmed by many investigators.

Many explanations have been offered to account for the magnetism of our planet. One theory assumed that permanently magnetized iron was present in the deep interior of the earth. This theory had to be discarded when it was shown that the earth's core was partly fluid and therefore could not hold permanent magnetism. It seems likely that permanent magnetism elsewhere in the earth's interior would not provide a sufficiently strong field.

In 1947, Patrick M. S. Blackett, of London University, suggested that any massive rotating body, such as the earth, generates a magnetic field purely as a consequence of the rotation. Laboratory experiments with large rotating objects did not reveal any such field. A test on the earth itself, conceived by Sir Edward C. Bullard and carried out by Keith Runcorn in deep mines, also failed to support Blackett's theory.

According to recent theories, material from the earth's mantle and core produce "hot spots" and special zones of movement near the crust.



It now seems to be practically certain that the magnetic field of our planet is generated by ordinary electric currents circulating in the earth's interior. Sir Harold Lamb pointed out in 1893 that such currents would have to be continuously supplied from some source of energy within the earth. It is natural to suppose that this would take place in the part of the earth where there is the least electrical resistance—that is, in the fluid outer core.

Walter M. Elsasser, a German-born American physicist, suggested in 1939 that current might arise in the core when materials of different electric properties and at slightly different temperatures came into contact. This is called the *thermoelectric hypothesis*. *Thermoelectricity* is produced by the unequal heating of an electric circuit composed of two dissimilar metals. In 1954, Runcorn suggested that there might be a thermoelectric effect at the boundary between the mantle and the outer core.

The most highly developed theory of the earth's magnetism at the present time is the *dynamo theory* of Elsasser and Bullard. It holds that a huge natural dynamo deep within the earth converts mechanical energy into magnetic energy. The mechanical energy would be supplied by a special type of fluid motion, called *convection*, carrying electric currents inside the outer core. Elsasser made elaborate mathematical calculations to show that such motion is possible. The dynamo theory of the origin of the earth's magnetism is considered to be the most promising of all at the present time.

Little by little a clearer idea of the earth's interior is emerging. We know something about the different regions into which it is divided and about the density, pressure, and elasticity at various depths. We have some idea of the chemical composition of the materials deep within our planet. We have at least made a promising start in solving the problem of how the earth's magnetic field is generated. Yet much remains to be learned about the earth before we reach the time when we know as much about the details of our planet's interior as we now know about its surface.


Gianni Tortoli PR

An infernolike view of Mount Etna during an eruption in 1971. Lava wells up from three fissures and converges as it flows down the side of the volcano

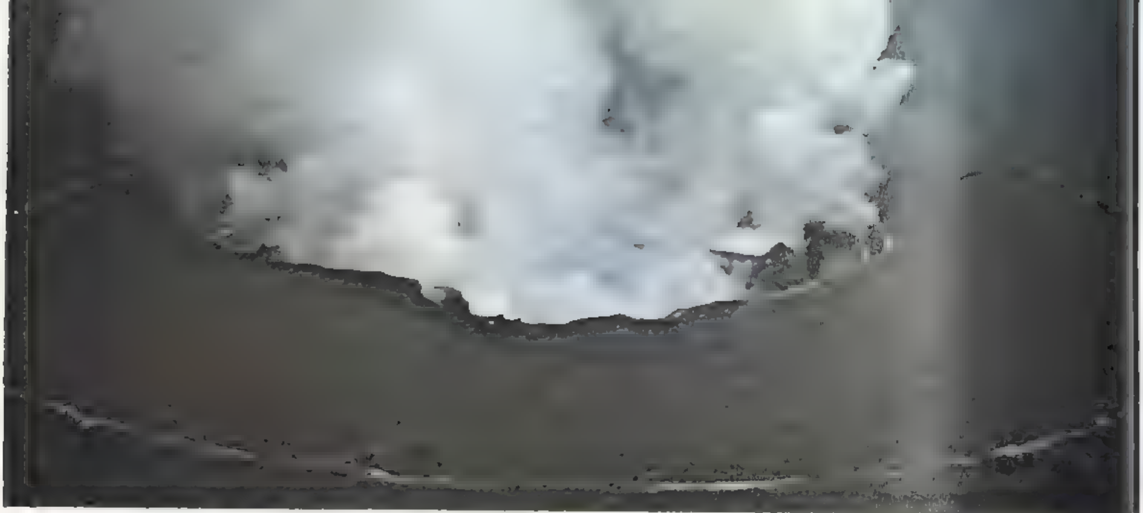
VOLCANOES AND GEYSERS

Volcanoes and geysers must be considered together because they are related. Volcanoes, however, are much more spectacular than geysers. In fact, they represent the most impressive display of natural forces, with the possible exception of earthquakes. All over the world volcanic craters are glowing and steaming and grumbling. Occasionally they devastate the land with clouds of fire and steam, with broadsides of boulders and rocks, and with rivers of lava and hot mud.

A volcano is a *vent* or *fissure* in the earth's crust. At intervals and more or less violently, hot solids, liquids, and gases emerge from it. The materials that issue from the vent sooner or later build up a *cone* about it. The term volcano is often applied, not only to the vent, but to the mountain itself. Volcanic mountains differ greatly in height and shape. Generally they are conical and often very lofty. Orizaba and Popocatepetl, in Mexico, Cotopaxi and Aconcagua, in the Andes, Mount St. Elias, in Alaska, Kilimanjaro and Kenya, in Africa, and Ararat and Demavend, in Asia, are all between 5,000 and 7,000 meters high.

Many of the conical peaks of volcanoes form unforgettable landmarks. Among these are the Peak of Tenerife, rising from the sea; Etna, girdled by the Sicilian surf; Chimborazo, in Ecuador; Mayon, in the Philippines; Mount Osorno, in Chile; and the Japanese peak of Fujiyama, or Fuji as it is often called, whose cone stands out in majestic isolation above the countryside.

The top of a volcano generally shows a more or less cup-shaped or basin-shaped depression. This depression is known as the *crater*. The characteristic conical shape of a volcano is undoubtedly due to the manner in which the mountain arises. It is an accumulation of solidified lava, rock fragments, and cinders ejected from the vent. The ejected material assumes the shape of a cone, with a pipe or funnel



D Cavillon/H Tazieff
Clouds rise up from a lava lake in the central crater of Nyiragongo, an active volcano that lies in Zaire near the border of Rwanda in Africa.

through its center leading to a cup-shaped cavity at the top. The angle of the cone depends on the viscosity or sluggishness of the lava flow and the cohesiveness of the material that has been thrown out. The more viscous the lava and the more cohesive the ejected material, the steeper the cone. The volcanoes in the island of Réunion, in the Indian Ocean, have been formed from very viscous lava, and they are steep. In the Hawaiian Islands, on the contrary, the cones were built up by fluid lava. They have a gradual slope. Their bases may be 100 kilometers and even more in diameter.

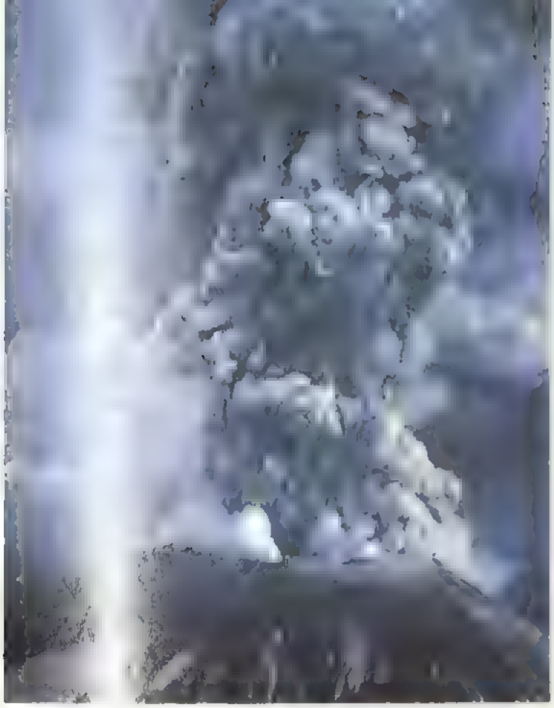
The composition of the cones of various volcanoes differs. Some are made up of cindery and slaglike fragments, others of sheets of lava, and still others of a mixture of both. The more massive volcanoes are usually built up out of alternating layers of lava sheets, rock fragments, and volcanic dust. Crossing these layers in various directions there are numerous cracks, filled with lava. It may seem hard to believe that volcanic mountains 4,500 or 6,000 meters high have been erected in this way, layer by layer. We must not forget, however, that this process has been going on for many thousands of years.

CHANGING SHAPE

Mountains that have arisen in this way are apt to be broken down as well as built up, and they may change their shape considerably in the course of their growth. Explosions may tear away part of the summit, as they did on Mount St. Helens in 1980. New vents and new cones may be formed. Over the centuries, Vesuvius has changed its shape many times. In the first century B.C., the summit of the volcano was a great depressed plain nearly five kilometers across. It was here that the gladiator Spartacus and his followers were besieged by a Roman army. After the great eruption of 79 A.D., which destroyed the cities of Pompei and Herculaneum, Vesuvius developed a huge crater, within which a new cone with a smaller crater was formed.

In 1822, a great eruption reduced the height of the volcano by 120 meters and produced a huge crater about one and one-half kilometers in diameter and 300 meters deep. By 1843, three small cones with craters had sprung up within the great crater. The eruptions of 1872 and 1906 again changed the shape of Vesuvius. In 1922, a new cone 70 meters high was built up within the old crater. All active volcanoes are subject to such changes in shape. The general effect of volcanic activity is to increase both the bulk and height.

Almost all great volcanoes develop new vents. These give rise to subsidiary, or "parasitic," cones, which tend to destroy the original conical shape. The volcanoes of the Hawaiian Islands have thousands of



Werth © Longview 1980/Woodfin Camp

The 1980 explosion of Mount St. Helens in Washington tore away part of the mountain, and emitted large amounts of gas, steam, and ash

subsidiary cones of this type.

The size of craters varies. As far as we know, there is little or no connection between the size of the crater and the height of the volcano. For example, the extinct Mexican volcano of Orizaba is 5,550 meters high. Its crater is about 300 meters in diameter. Popocatepetl is not quite so high—5,450 meters, yet its crater is about twice as large as that of Orizaba. Haleakala, a volcano in the Hawaiian Islands, is only about 3,000 meters high; its crater is 32 kilometers in circumference. There does not seem to be any connection, either, between the size of the crater and the explosive potentialities of the volcano in question.

CALDERAS

The name "caldera" has been given to very broad and comparatively shallow craters. This word is Spanish and means "caldron." It was first applied to a very large pit in the Canary Islands—a pit about 5 kilometers in diameter and surrounded by cliffs that rise to a height of some 900 meters. A caldera results from the explosion or collapse of a former volcanic cone, causing the crater to become wider and shallower.

There are many calderas and some of them are huge. That of Mauna Loa, on the island of Hawaii, is a bit more than five and one-half kilometers long and about three kilometers wide. The caldera of Kilauea, on the same island, is four kilometers long and about three kilometers in width. Both of these immense calderas were formed by the collapse of the old volcanic cones.

Many calderas become filled with water, forming lakes. Among the most beautiful and picturesque of these is Crater Lake, in what is now the Crater Lake National Park in southwestern Oregon, on the crest of the Cascade Mountains. Crater Lake is over 1,800 meters above the level of the

Volcanologists kept a careful watch on earth movement, magnetic and temperature changes, and other indications of possible new activity in Mount St Helens, but the volcano remains unpredictable

John Marshall/Aperture PhotoBank

H Tazieff

Kilauea crater of Hawaii spews out a fountain of red hot rock fragments. Earthquakes often occur along with eruptions of Kilauea.

sea. It is nearly circular in form and is surrounded by rock walls that range in height from 270 meters to 670 meters. The lake is about eight kilometers in diameter and in some places it is some 600 meters deep. The Indians called it "Sea of Silence." To the American poet Joaquin Miller, it was "a sea of sapphire set around by a compact circle of . . . grizzly rocks."

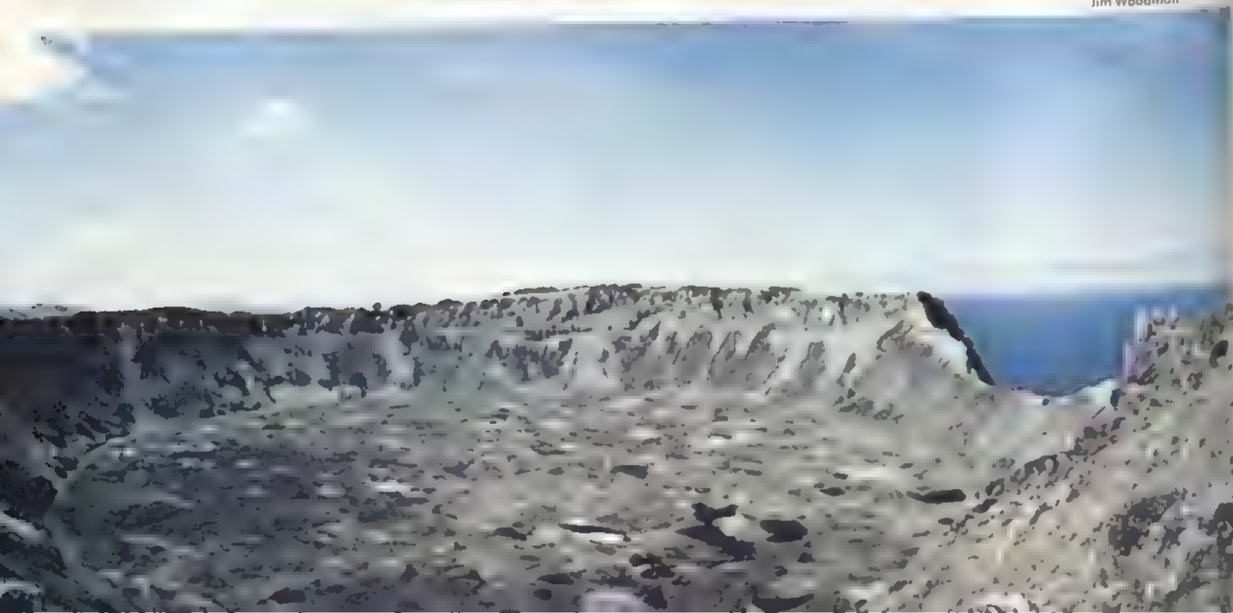
SOME ACTIVE, SOME EXTINCT

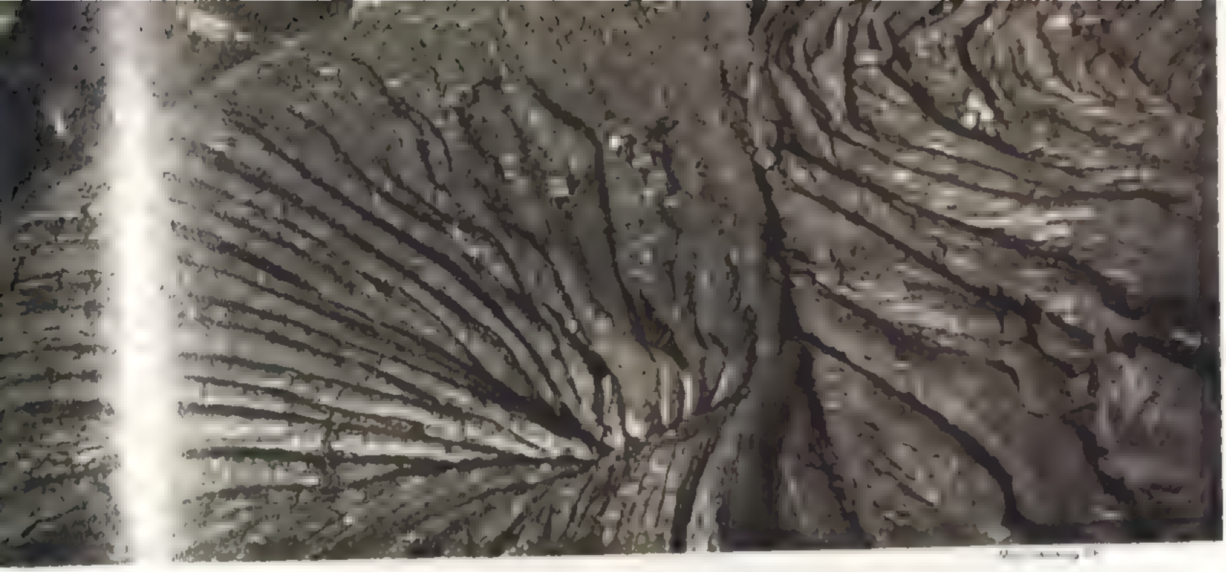
Volcanoes vary greatly in activity. As a rule, periods of partial or complete inactivity alternate with periods of explosive violence. Until the eruption of 79 A.D., Vesuvius had been in repose for centuries. The eruption of Krakatoa in 1883 took place after an inactive period of two hundred years. Some volcanoes are constantly active. Stromboli, a volcanic island in the Mediterranean, off Italy's Lipari Islands, has been pouring forth lava for more than 2,000 years. Izalco, in El Salvador, has erupted ever since 1770. Volcanoes of this type are relatively tame.

Certain volcanoes are entirely or almost entirely extinct. Among these are the great volcano of Palma, in the Canaries; Mount Shasta, in California; Mount Hood, in Oregon; and Mount Rainier, in Washington. The peaks of certain dead volcanoes are snow-clad. Their slopes have been carved by erosion to such an extent that they are fast losing their characteristic shape. In some instances, the forces of erosion have worn down dead volcanoes almost to their foundations.

Rano Raruku crater in southeastern Easter Island Volcanic rocks from the slope of this crater were used to make some of the well-known Easter Island statues

Jim Woodman





[illegible] from a 1969 Hawaii eruption. This twisted, ropy appearance is characteristic of very liquid *pahoehoe* lavas when they harden.

MUD VOLCANOES

Sometimes, gas issuing from a vent at the surface of the earth may carry particles of sand and clay with it. In the course of time, a cone may be built up from these particles. If they are moistened by heavy rainfall, they will form mud. This will dry and harden at the surface of the mound. The gas will accumulate under the hardened surface. The pressure will build up until finally the gas will blow off the top of the cone. These *mud volcanoes*, as they are called, are frequently found in oil and gas fields. Some arise in regions where volcanic steam escapes through mud. Certain mud volcanoes rise to considerable heights — that of Bog-Boga, in the Baku region of the Soviet Union, is more than 30 meters high.

DISTRIBUTION OF VOLCANOES

There are several thousand volcanoes in the world, and about 450 of them are known to be alive. They are distributed in a series of belts. The great belt of the Atlantic Ocean includes a considerable number of volcanic islands. Among them are West Spitsbergen, Jan Mayen Island, Iceland, the Azores, Madeira, the Canary Islands,

Mount Ruang, which rises approximately 3,300 meters, is one of several volcanoes on Java.

Iceland, sitting on one of the earth's ... has many geysers. The top phot... hot sulfur vent, or fissure, at Lake M... Left, a true geyser, a spouting tower of steam also in Iceland

and the Cape Verde Islands. Another volcanic belt extends southward from Saudi Arabia. It takes in the Red Sea, Ethiopia, and the large island of Madagascar

A line of volcanoes may be traced along the eastern side of the Pacific Ocean from the Aleutian Islands to Cape Horn. There are many active volcanoes in the Aleutian and Coast ranges of Alaska. Katmai Volcano erupted as recently as 1912, when it blanketed Kodiak Island with lava and ash. The Cascade Range, in the United States, has many volcanoes, but up until the eruption of Mount St. Helens in 1980, they had been inactive since 1914. Mount St. Helens poured clouds of steam, gas, and ash over western Washington state, and still "acts up" occasionally. Other active volcanoes stretch across Mexico from Colima to Tuxtla. Popocatepetl, in central Mexico, gives off clouds of sm...

A series of volcanoes in South America begins with the Nevado del Tolima, in Colombia, and continues down to Corcovado Volcano, in southern Chile. Cotopaxi, in Ecuador, is 5,900 meters high. It is probably the highest active volcano

Another line of volcanoes swings from the Bering Strait to the west side of the Pacific Ocean and then runs down to the Indian Ocean. Kamchatka Peninsula has about fourteen active volcanoes. The islands of Japan are a long volcanic mountain chain lifted above the ocean. The string of volcanoes passes through the Philippines, the Moluccas, and the Sunda Islands to New Guinea

ADDING SURFACE MATERIAL

The condensation of the enormous amounts of steam rising from even small active volcanoes results in the addition of considerable quantities of water to the earth's supply. It is estimated that during a single eruption of Mount Etna nearly 2,270,000,000 liters of water were given off as steam. A small parasitic cone of the same crater yielded about 1,740,000,000 liters in a hundred days. The steam that issues from volcanic vents is believed to come partly from ground water that has seeped far into the earth and that has become superheated and partly from the wa

ter that was present in the rocks when they were formed.

Volcanoes have pushed out incredibly great masses of solids from the earth. All volcanoes owe their mass to the interior of the earth. Whether extinct or active, 100 or [illegible] meters high, or towering to a height of nearly 10 kilometers, volcanoes have been responsible for adding enormous amounts of material to the surface of the earth. The average annual discharge of sediment by North America's Mississippi River is some 560,000,000 metric tons. In a few hours, during the eruption of 1902, Mount Pelee belched out five hundred times as much in the form of volcanic dust.

WARNING SIGNS

There are usually a number of warning signs when a volcano is about to erupt. There are earthquakes and loud rumblings, like those of thunder. These rumblings are probably caused by the movement of gases and molten rock, held in under great pressure. Hot springs may suddenly appear in the vicinity of a volcano shortly before an eruption takes place. There may be a considerable increase in the activity of the volcano. The level of nearby lakes may rise or fall appreciably, or the lakes may be entirely drained of their water.

THE ERUPTION ITSELF

Then the eruption proper takes place. Out of the crater rush enormous quantities of superheated water vapor and other gases, carrying with them vast quantities of rocks, stones, ashes, lava, and other materials. The ground shakes violently and there is a tremendous roaring sound. It is said that the roar that accompanied the 1815 eruption of Tambora, a volcano on Sumbawa Island in Indonesia, could be heard at a distance of 1,500 kilometers.

The column of gases and solid particles issuing from a volcano in eruption goes up vertically to a great height. The friction of the particles issuing from the vent creates static electricity. Forked lightning flashes to and fro and peals of thunder are heard. The rising column may be lit up by the glowing lava in the crater so that it seems to be aflame. In some cases, the column that arises from the crater is so dense that it hides the sun and creates impenetrable darkness. The condensation of the steam as it rises aloft brings about torrential rain

VOLCANO

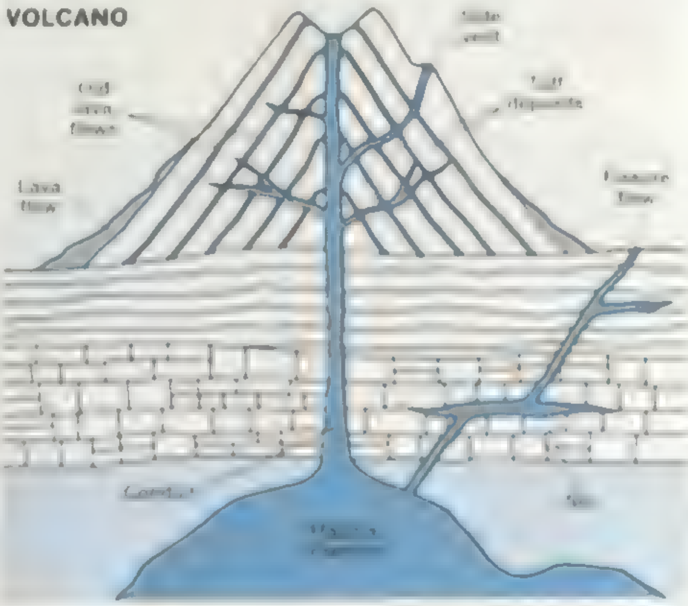


Diagram of a volcano showing how magma, or molten rock from the interior passes through overlying layers of rocks through a fissure or vent to erupt at the surface spewing out lava. The lava accumulates around the opening, often forming a mountain. The central depression atop the volcanic mountain is the volcano's crater.

The downpour is also partly due to the condensation of moisture-laden air, drawn upward to high altitudes by the updraft created as volcanic gases are discharged. As the rain falls in torrents, muddy rivers flow down the slopes of the volcano. They may bury cities at the base of the mountain.

VOLCANIC GASES

By far the greatest part of the gases that issue from volcanic vents is made up of steam—superheated water vapor, which may attain a temperature of more than 500° Celsius. Other gases present may include hydrogen chloride, carbon dioxide, carbon monoxide, methane, hydrogen, oxygen, and argon, all at a high temperature. Various compounds of sulfur, such as hydrogen sulfide and sulfur dioxide, are given off by some volcanoes. Gases are emitted not only from the volcanic vent itself, but also from lava flows. These flows may continue to emit gases for weeks or even months after the eruption.

LAVA

In some ways, lava is the most characteristic product of a volcanic eruption. It is true that in some cases, as in the great eruption of Mount Pelée in 1902, no lava at all is ejected. As a rule, however, after the volcano has "cleared its throat" with the discharge of superheated steam and other gases, lava begins to flow from the crater or even to spout high in the air like a fountain of molten metal. Usually the lava pours over the edges of the crater or from fissures in the sides of the volcano. Where there are a great many fissures, the volcano seems to "sweat" lava from numerous pores.

PLUG DOMES

In some cases, when lava is pushed out from the volcanic vents, it is too viscous to flow, either because of its comparatively low temperature or its low gas content. Hence it is piled up in the form of great domes over the vents. These volcanic edifices are called *plug domes*. In Lassen Volcanic National Park, there are thirteen domes of this type within an area of approximately 130 square kilometers.

An unusual type of plug dome appeared on Mount Pelée after the disastrous eruption of 1902. The lava that filled the vent after the eruption became hardened into rock at the surface. The interior was highly viscous, however, and the whole mass was gradually pushed up until it formed a tower over 300 meters in height above the summit of the volcano. It was called the spine of Mount Pelée. Eventually it crumbled away, largely as the result of explosions of gases within it. Another plug was formed in a series of eruptions of Mount Pelée from 1929 to 1932.

Tony Gauba, Audubon PR

Lava that is too viscous to flow piles up in great domes or towers forming a volcanic neck or plug. Here a volcanic neck known as Shiprock in northwestern New Mexico.

HOW LAVA FLOWS

The rate of flow of the lava that issues from the earth is often rapid at first. It varies with the viscosity of the lava and the slope of the land. When the lava reaches a steep downward slope, it pours tumultuously over it. On gentle slopes, however, it may move very slowly. As the lava cools, it becomes more viscous and its flow becomes much more sluggish.

The surface appearance of the cooled lava depends in part on its chemical composition, which determines whether the resulting rock will be a basalt, rhyolite, or andesite. The nature of the lava flow is another extremely important factor. Lavas that are particularly viscous break up, as they cool, into multitudes of rough blocks. These grate together as the lava continues to flow and they are often piled up in heaps or mounds. When the flow finally stops, the result is an exceedingly irregular formation—an accumulation of sharp-edged blocks and jagged fragments. Rough lava of this kind is called *block lava*. It is sometimes known by the Hawaiian name *aa*. When more fluid lava hardens, it shows a twisted, ropy structure with a varicolored and satiny surface. The Hawaiian word *pahoehoe* is used for this corded lava.

Lava is red-hot or white-hot when it first issues from a crater. It is a poor conductor of heat and cools very slowly. Consequently, after the surface crust has formed and has become cool enough to be walked on, the lava may be red-hot below. Many examples might be given of the slowness with which lava cools. In 1830, steam was still issuing from lava that had flowed from Etna, in Sicily, forty-three years before. The volcano of Jorullo, in Mexico, discharged streams of lava in 1759; eighty-seven years later, two columns of steam still rose from the lava.

VOLCANIC ROCKS

Besides lava, as we have seen, volcanoes discharge huge quantities of rocks, stones, cinders, and ashes. During the eruption of 1779, mighty Vesuvius hurled cinders to a height of 3,000 meters. In 1815, Tambora, in the Indonesian island of Soembawa, or Sumbawa, covered the sea for many kilometers with such huge quantities of pumice stone that ships could hardly force their way through it. Cotopaxi, a volcano in north central Ecuador, is said to have flung a two hundred metric ton block fourteen and one-half kilometers.

The accumulation of lava and rocks and sand in the vicinity of a crater sometimes reaches almost unbelievable proportions. The creation of the volcano known as Parícutin offers a striking example.

On February 20, 1943, there was a severe earthquake in the state of Michoacán, Mexico, some 290 kilometers west of Mexico City. Following the earthquake a crater appeared in a corn field and began to belch forth rocks and sand. Later it emitted immense streams of lava. The accumulation of volcanic materials about the crater mounted with fantastic speed. Soon a new volcano, Parícutin, was born. Within the space of a year its height was more than a third that of Vesuvius, which had been many thousands of years in the making.

ASH AND STEAM

A vast amount of dusty ash is emitted from volcanoes. When Tambora erupted in 1815, ash dropped on Borneo, 1,400 kilometers away, in vast quantities. During the eruption of Cosigüina, or Consegüina, in Nicaragua, it is estimated that some 4,740,000,000 cubic meters of ash were cast to the winds and were carried at least 1,300 kilometers. In 1980, more damage was done from ash emitted from Mount St. Helens than from the eruption itself. Ash from the eruption of Krakatoa, in 1883, darkened the sky for 240 kilometers from the site of the eruption and fell in appreciable quantities 1,500 kilometers away.

The ash in the vicinity of an erupting volcano produces eerie darkness, penetrated only by flashes of light from the crater and the glow and glare of molten lava. Later the ash produces startlingly beautiful effects in the skies. As it floats aloft, sometimes making several circuits of the globe, the fine volcanic ash refracts or reflects the individual colors of sunlight and thus brings

about gorgeous sunrises and sunsets all over the world.

The deluge of water from the condensed steam of the eruption often converts the volcanic dust into a sticky mud that overwhelms and buries everything in its path. The ancient Roman city of Herculaneum was buried during the eruption of Vesuvius in 79 A.D. by such an inundation of mud. The great eruption of Cotopaxi in 1877 covered many villages with a deposit of mud, mixed with lava and various kinds of debris. Whole forests were laid low as a consequence of the eruption.

UNDERWATER VOLCANOES

The submarine volcanoes of the world are among the most spectacular of all. Etna, Stromboli, the Peak of Tenerife, and many other volcanoes had their birth under the sea. Nobody knows how many active volcanoes are now at work in the ocean depths. Often they throw up cinders and steam and agitate the surface of the sea. Vast outpourings of lava on the ocean floor accompany these eruptions. Sometimes layer upon layer of lava is formed and at last an island appears above the ocean surface. The volcanic chain of the Hawaiian Islands was created in this way.

BIRTH OF VOLCANIC ISLANDS

Occasionally, submarine volcanoes betray their presence in a most striking way: through their action a new island is suddenly thrust up or an old island sinks below the surface. This action is quite different from the gradual deposition of lava.

The Mediterranean Sea has often witnessed the sudden appearance and disappearance of new volcanic islands. In 1831, a new islet, called Graham Island, suddenly appeared between Sicily and Africa as a result of volcanic action. This island reached a height of 60 meters above water and attained a circumference of something like five kilometers. Since it was composed of loose materials, it could not withstand the constant pounding of the sea. It was rapidly eroded by the waves and in a few brief months it was reduced to a shoal, called Graham's Reef. New islands are thrown up quite frequently between Sicily and Greece, but they generally disappear almost as quickly as they arise.

Some islands that have been thrown up by submarine volcanoes are more permanent. Three islands of the Bering Sea are good examples. One, called Bogoslof Island, appeared about 65 kilometers west of Unalaska Island in 1796 after an eruption. In 1883, another eruption threw up a volcanic cone of black sand and ashes, known as New Bogoslof, or Fire Island. Still another made its appearance in 1906.

In 1963 a volcanic island, later named Surtsey, appeared off Iceland's southwest coast near the Vestmannaeyjar Islands. By now the island is about two and one-half square kilometers and more than 150 meters high.

FISSURE ERUPTIONS

Not all the materials that are ejected from the earth are piled up to form mountains. In many instances, lava flows out of fissures in the earth's crust and spreads over large areas without producing anything suggesting volcanic cones. Such outpourings are called *fissure eruptions*. The American geologist H. S. Washington suggested that they should be called plateau flows, because the area they cover is as flat as a plateau. The lava that issues from fissure eruptions, or plateau flows, is not very viscous.

Fissure eruptions have taken place on a vast scale. In the Deccan region of western India, an area of more than 500,000 square kilometers has been covered with lava, which is 600 meters thick in certain places. Parts of Washington, Oregon, Idaho, Montana, and California lie under a sea of solidified lava about 575,000 square kilometers in area and with an average depth of 150 meters. Similar flows have covered large regions in the northern part of Wisconsin and Michigan and along the northern shores of Lake Superior. Some 100,000 square kilometers in England were at one time under a sea of fissure lava. Large tracts in Ethiopia are covered with such lava.

Fissure eruptions have been common

in Iceland, an island that has been built up to a great extent by volcanic activity. In 1783, two streams of lava issued from a fissure, and they flowed 65 and 45 kilometers respectively. Iceland's lava desert of Odadahraun, which covers an area of more than 3,500 square kilometers, is also a product of fissure eruptions.

WHY ERUPTIONS OCCUR

A volcanic eruption or an outpouring of lava in a fissure eruption is due to the heat within the earth. We do not fully understand the origin of this heat. Some geologists maintain that it is a residue of the original molten state of the entire earth during the early period of its formation. The earth's internal heat has been retained for so many millions of years, they say, because rocks are such poor conductors of heat. Other geologists maintain that heat is produced because of the breaking down of radioactive elements such as uranium and thorium. Both of these elements are present in all rocks, though generally in very small quantities.

Whatever the source of the earth's heat, it is great enough to liquefy vast masses of rock. This molten material, called *magma*, consists mostly of solutions of silicates with oxides and sulfides. It also contains steam and other gases, held in solution by pressure. Where this magma forms, the liquid rock weighs less than the adjacent solid rock, and the gases dissolved in it make it even lighter.

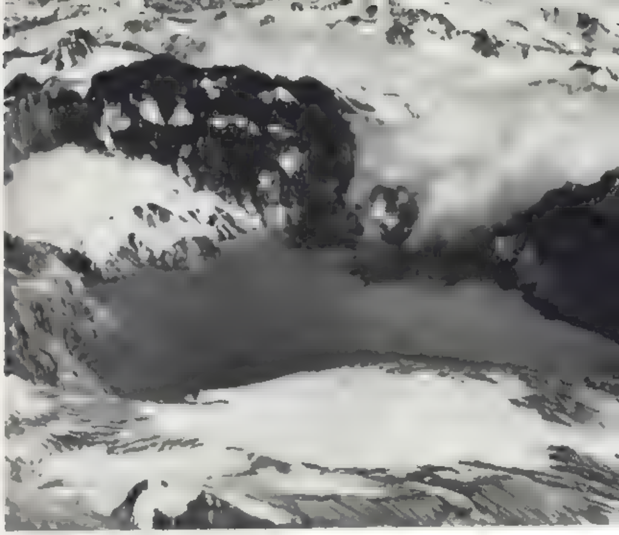
The magma is subjected to the pressure of the heavier rock that surrounds it and it is forced upward. Some of it reaches the outer part of the earth's crust and ultimately makes its way to the surface through fissures or vents. The molten materials are then hurled aloft by the explosive forces within the earth, or else they flow out from craters or fissures in the form of more or less viscous lava. Lava is simply magma that has reached the surface of the earth—magma from which most of the gases have escaped.

GEYSERS

Geysers are jets of boiling water issuing from the earth in a few volcanic regions. The term is derived from the Icelandic word, "geysir," meaning "to burst out in violence." The true geyser is a spouting tower of glistening steam, often rising several hundred meters or more in the air, persisting anywhere from a few moments to an hour or more. It gushes forth in an area of extensive hot springs. There are only three principal regions where geysers are known to exist: Iceland, New Zealand, and Yellowstone National Park in North America. Of these three, Yellowstone has by far the most impressive display of geysers.

YELLOWSTONE

The steam-jet wonderland of Yellowstone was probably first glimpsed by an official exploring party in 1807, at the time of the Lewis and Clark Expedition to the Northwest Territory. Subsequently trappers and scouts explored the Yellowstone and reports were sent back to Washington from time to time. Despite the accumulating information about geysers, Easterners remained skeptical about their existence. In 1870 Nathaniel Langford published in *Scribner's Monthly* a narrative of a several weeks' trip through the Yellowstone region. Langford's stirring description of Firehold Valley with its 3,000 boiling springs, its one hundred turbulent geysers,



Steve McCutcheon, Alaska Pictorial Service

Emerald Lake has formed in the crater, or depression, atop volcanic Mt. Katmain in Alaska. Snow covers the surrounding region

its many fountains of dazzling steam, was scornfully dismissed as "balderdash" by armchair experts in the East. Langford himself was denounced as the "champion liar of the Northwest." When David Folsom, who had taken a similar trip in 1869, attempted to publish his experiences, he received a most ironic note from *Lippincott's Magazine:* "Thank you, but we do not publish fiction!"

Nevertheless, interest in the unique natural marvel of Yellowstone continued. The official report of Gustavus C. Doane, 2nd Lieutenant, 2nd U. S. Cavalry, himself a member of the Langford party, proved to be the most comprehensive survey ever made of the Yellowstone. A movement began to incorporate the territory into the national domain. No worse time could have been chosen. The country was in the grip of the scandals of the Grant Administration and there was strong pressure on Congress to throw open the Yellowstone to private exploitation. To the credit of the U. S. government, the area was saved for the permanent benefit of the entire people.

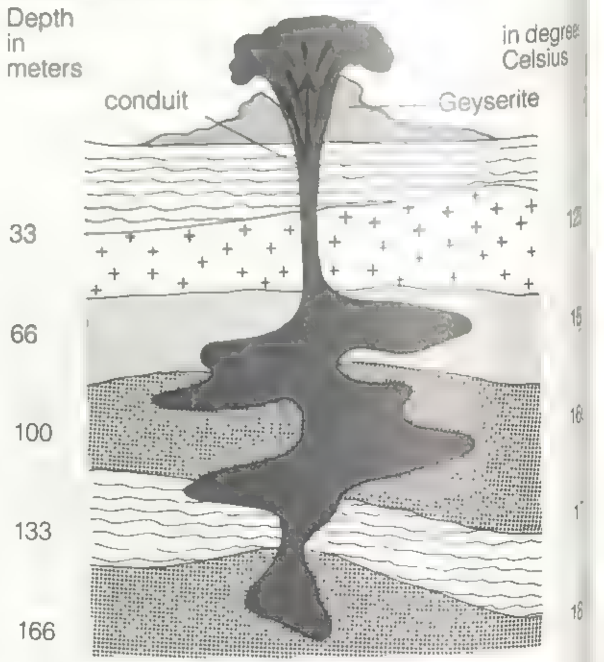
On March 1, 1872, Congress passed the Act creating Yellowstone National Park as a "public pleasure ground and game preserve." Nathaniel Langford was appointed the first superintendent of this magnificent wildlife sanctuary. At the present time, Yellowstone National Park has a total area of 8,850 square kilometers. It is almost three times the size of the state of Rhode Island.

In the seventies, a British visitor, the fourth Earl of Dunraven, traveled through Yellowstone following a big game hunt with Buffalo Bill and Texas Jack. Dunraven stood in awe before Firehole Valley and the fury of the geysers, the Giantess, the Castle, Old Faithful, and the Grand Geyser. This last flung a column of steam nearly 30 meters high, from the apex of which spouted five torrential jets to a height of about 75 meters from the ground.

In *The Great Divide,* published in 1874, Dunraven described Castle Geyser in the following words: "[We] could hear a great noise . . . Louder and louder grew the disturbance, till with a sudden qualm he would heave out a few tons of water, and obtain momentary relief. After a few premonitory heaves had warned us to remove to a little distance, the symptoms became rapidly worse; the row and the racket increased in intensity; the monster's throes became more and more violent, the earth trembled at his rage; and finally, with a mighty spasm, he hurled into the air a great column of water. I should say that this column reached at its highest point of elevation, an altitude of 250 feet [76 meters]. The spray and steam were driven through it up to a much greater elevation, and then floated upwards as a dense cloud to any distance. The operation was not continuous, but consisted of a strong, distinct pulsation, occurring at a maximum rate of seventy per minute, having a general tendency to increase gradually in vigor and rapidity of utterance until the greatest development of strength was attained, and then sinking again by degrees. But the in-

Geysers erupt when ground water in a vertical fissure comes into contact with volcanic heat and is raised to its boiling point.

GEYSER ACTIVITY



crease and subsidence were not uniform or regular; the jets arose, getting stronger and stronger at every pulsation for ten or twelve strokes, until the effort would culminate in three impulses of unusual power. . . . The volume of water ejected must have been prodigious; the spray descended in heavy rain over a large area, and torrents of hot water, six or eight inches [15 or 20 centimeters] deep, poured down the slopping plateau."

In the Middle Basin of the Firehole region is "The Devil's Paint Pot," a caldron of boiling, many-hued mud, which bubbles and steams with a wonderful play of changing colors.

The hot water ejected by geysers is always beautifully clear, but still it is highly charged with mineral matter, mainly dissolved silica. Around the orifices of geysers the incrustations of such materials often assume beautiful or fantastic forms and colors. Thus, the Castle Geyser has made a beautiful white cone for itself, and the Great Fountain Geyser a broad, circular pedestal about 60 centimeters high. The tints assumed by the mineral deposits are produced by algae, which grow luxuriantly in the hot water.

ICELANDIC GEYSERS

Though Yellowstone Park boasts of the most numerous and famous geysers, Iceland, the birthplace of geyser study, must not be passed by without notice. This country is itself one of the wonders of the world. It is a land of fire and ice, of glacier and geyser, of lava and slush, of avalanche and volcano.

From the top of Odahahraun, there is a lava field extending over 3,650 square kilometers. All together, almost 12,000 square kilometers of the island are black with lava, and 13,340 square kilometers are white with snow. Rising from this black-and-white desert are great volcanoes, such as Hekla (1,560 meters). Most of the volcanoes are quiescent now, but Askja, whose crater is 87 square kilometers in extent, and 900 meters deep, was in eruption in 1875, and covered more than 5,000 square kilometers with its ashes.

John Lewis Stage PR

Blowholes, or minute craters formed on the surface of thick lava deposits, are found along the coast of Tongatupu, an island in the South Pacific.

The Great Geyser has built a mound of siliceous material for itself about 12 meters high, and from the saucerlike basin on its top a tube three meters in diameter descends about 23 meters. In its prime, it used to eject water to the height of 45 meters, but now the average height of its jet is only 20 or 25 meters. The sound of the geyser in eruption has been compared to the roar of an angry sea, intermingled with the regularly recurring sounds of guns.

The Strokkr has no regular basin, merely a funnel-shaped tube, narrowing from a diameter of 2.5 meters at the surface to 25 centimeters at 13 meters down. It can usually be made to erupt by throwing in turf or stones, the amount thrown in regulating the time of eruption. The Strokkr can spout higher than the Great Geyser, but its usual height is only 9 to 12 meters.

NEW ZEALAND GEYSERS

A third great geyser wonderland is found in the North Island of New Zealand, in the volcanic country around Lake Taupo and Rotorua. Here we find the greatest geyser in the world. Its tube, 24 meters deep, is situated in the middle of a hot lake

lying in a crater formed during the great volcanic eruption of 1886. This tremendous geyser has not the beauty of the Yellowstone Park geysers, since the column of water it flings is muddy and inky-black, but it surpasses the Yellowstone geysers in violence. It often throws its water column to a height of 150 meters, and on one occasion three times that height. At times it is dormant for weeks; at other times, it is active for weeks. Near Rotorua there are a number of geysers, but only the smaller ones are now active. The Wairoa Geyser, which used to spout spontaneously to a height of 60 meters, now plays only when fed with bars of soap.

It has been found that the addition of certain alkaline substances, such as soap or lye, makes the water somewhat viscous, causing it to retain the smaller steam bubbles till the accumulated volume of steam breaks out with increased eruptive power and a sudden lowering of pressure. Before the great eruption of 1886 two geyser lakes, by their overflow, had produced a set of marvelous siliceous incrustations known as the White Terrace and the Pink Terrace. At the eruption, these beautiful formations were destroyed.

WHY THEY ERUPT

What causes the eruption of geysers to take place? The famous 19th century German chemist Robert Wilhelm Bunsen developed a quite satisfactory theory to account for the phenomenon. The Bunsen theory of geyser eruption is still pretty generally accepted.

It is based on the fact that the boiling point of water is raised as the pressure is increased and is lowered as the pressure is decreased. Water will boil at a temperature of 100° Celsius at sea level, where the atmospheric pressure is about 1 kilogram per square centimeter. The pressure will be twice as great at a depth of ten meters. At this depth the water will boil at a temperature of 120° Celsius.

If ground water penetrates into a more or less vertical fissure deep within the earth, it will form a liquid column as it accumulates. As the bottom of the column comes into contact with volcanic heat, its temperature will rise quite a bit above 100° Celsius, which, as we have seen, represents the boiling point of water at sea level. However, it will not boil at first because it is subjected to the pressure exerted by the column of water above it and its boiling point is raised.

As the water at the bottom of the column becomes hotter, a part of it will be turned into steam. The pressure that is exerted by the steam will cause the water column to rise, and some of it will overflow at the surface. This will mean that less water will press down upon the water at the bottom; the pressure will be decreased and the boiling point will be lowered. The result will be that more of the water will be converted into steam. At last the accumulating steam will blow the whole column of water out of the fissure; an eruption of the geyser will take place. The phenomenon will be repeated with more or less regularity according to the supply of water and heat.

CAN WE USE THE ENERGY?

The tremendous heat energy of the earth that is the source of all volcanic and geyser activity is known as *geothermal energy*. Man has begun to control this energy and use it for his own needs.

Heating from underground sources is used extensively in Iceland, to a limited extent in New Zealand, Japan, and the Soviet Union, and in a few spots in the United States. It is, however, for generating electricity that geothermal energy is receiving the most attention as a fuel source. Basically, the steam from a geothermal field is used to run a turbine which drives a generator to produce electricity.

The commercial application of geothermal energy for generating electricity began in the early twentieth century in Italy. Today electric power is produced from geothermal sources in New Zealand, Japan, the United States, the Soviet Union, Italy, and Iceland. The largest known geothermal field is The Geysers, in California, north of San Francisco.

For a more detailed discussion of this energy source, see the article "Geothermal Energy" in *The New Book of Popular Science*.

Bob and Ira Spring/Alpha

Spanning millions of years, the imperceptible process that formed the Alps began with sedimentation beneath the sea, then upheaval and erosion

MOUNTAINS

The poetic phrase "the eternal hills" is quite apt if we consider it in terms of the short span of human life. Viewed from the standpoint of geologic time, however, the oldest mountain range endures no longer than a single night's dream in a human lifetime. From Pre-Cambrian times down to the present, the perpetual process of building and destroying mountains has continued. Massive mountain ranges called *cordilleras*, like the far-flung Andes, may be the products of millions of years of sedimentary deposit and buckling of the earth's crust. The volcanic cone of Kilimanjaro in Tanzania, on the other hand, probably came into being with comparative abruptness, like the volcano of Parícutin, Mexico, which was formed in 1943.

HOW MOUNTAINS FORM

Geologists call mountain building *orogeny*, from two Greek roots meaning "the rise of mountains." Three different kinds of processes are involved. In the volcanic process, isolated peaks are thrust up as the earth's internal heat pressure comes into play. Volcanic action occurs more often in ocean depths than on land, and some submarine volcanoes occasionally break through the surface. The second process is that of denudation and erosion by which high plateaus are gradually shaped into peaks and ridges by the denuding effect of the elements and the erosive action of rivers. A good example of an original plateau now worn into the form of moun-

tains is the Catskill range in southern New York State. The Grand Canyon of the Colorado reveals the operation of erosion on the plateau above the Colorado River. In a few million years the entire area will have been formed into peaks and clefts.

The third way in which mountains arise is through the deposit of successive layers of sediment, either on the floor of a shallow sea or in a broad trough of sinking land known as a *geosyncline*. In the course of successive geological epochs, this sediment accumulates to such an extent that severe stress is created in the earth's crust. Other factors, such as the heat pressure in the interior of the earth and the presence of radioactive elements in the surrounding rock, may also affect the gradual upthrust of sedimentary deposit. The process is a lengthy one, probably alternating between periods of slow rise and sudden upthrusting.

The Appalachian mountains of the eastern United States were once a mass of geosynclinal sediments, such as we described above. More than 500,000,000 years ago, the present site of these mountains was occupied by a narrow trough or geosyncline, filled with the waters of the sea. Immediately to the east of the trough was an ancient landmass, to which the name Appalachia has been given by geologists. Present opinion holds that Appalachia was probably a series of islands forming an arc off the eastern coast of North America. It is thought that Appalachia supplied most of the sediments to the sea that stretched between the island arc and the large continent to the west.

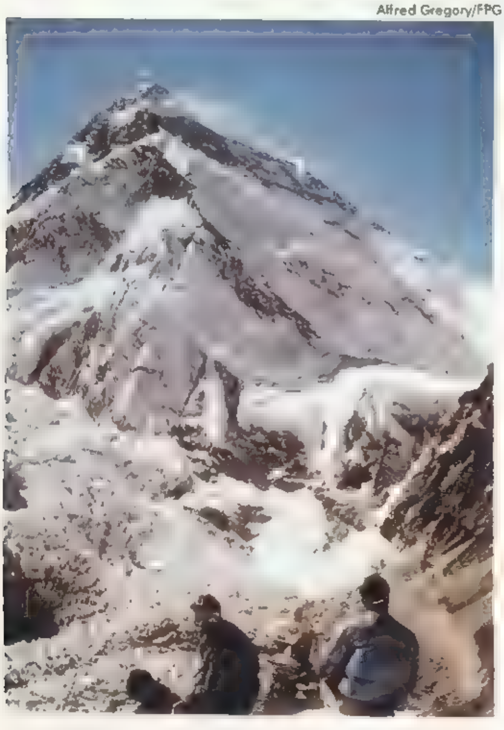
As the trough was filled with the debris eroded from the mountains and plains of Appalachia, its sediments turned into rocks. Following a few minor episodes of mountain building, powerful forces within the earth tended to shrink these rock beds, causing the rocks to wrinkle, or *fold*, and to gradually become uplifted into *fold mountains*, not once but several times. Erosion brought the peaks low after each uplift. The present Appalachians are worndown remnants of mountain chains that may once have rivaled the Himalayas in splendor.

Evidence for these mountain-making processes is conclusive. Fold mountains are composed primarily of bedded sedimentary rocks that often contain fossilized remains of sea animals and plants. After many fruitless attempts to explain these fossils in other ways, scientists have gradually come to accept them as proof of the origin of certain mountains, or their remnants, from rocks formed under water. The mountains themselves need not have arisen from the depths of the sea, which may have vanished from the area before mountain building began in earnest.

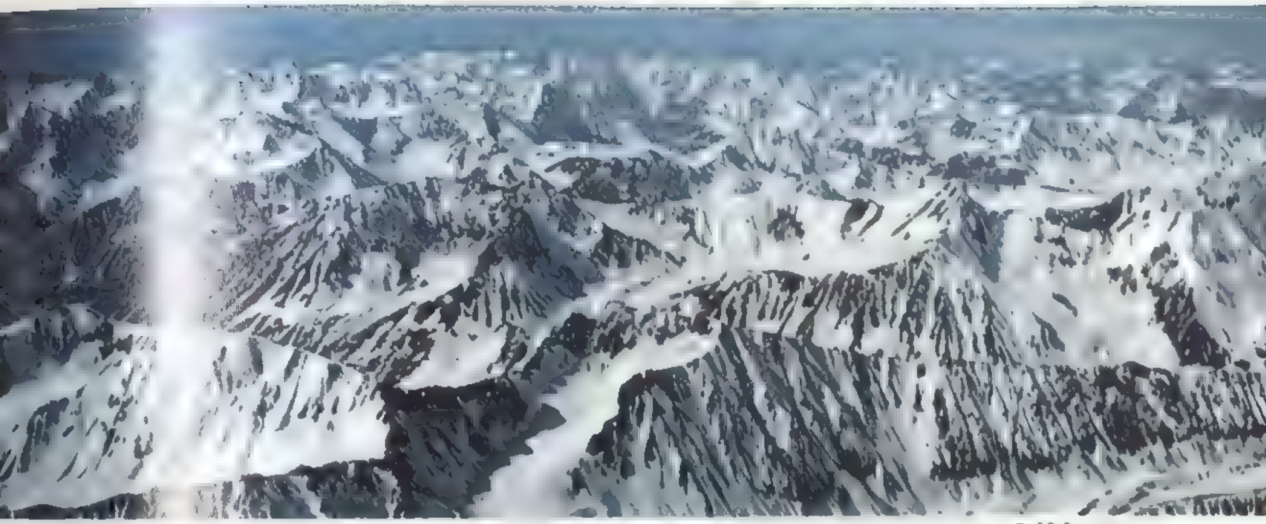
RAW MATERIAL

Sediments may be regarded as the raw material of orogeny. They represent the rock fragments and soil weathered from already existing lands and mountains and carried by rivers into the sea, where they

Alfred Gregory/FPG



Mount Everest, highest mountain peak in the world, is a recent development on the geologic time scale.



Dr E R Degginger

Folded compressed sediment forms the Alaska Range, home of Mt. McKinley.

slowly accumulate layer upon layer. When several kilometers of sediments have gathered on top of each other in a mass many kilometers long, much of it already hardened into rock, the main mountain-making process starts. It is intermittent at first, but finally reaches a grand climax of folding, upthrusting, and *faulting*, or cracking.

From where has all this sediment come? To answer this question, let us consider present-day erosion processes. By way of example, the Ganges and Brahmaputra rivers of India and the Mississippi River in the United States together contribute nearly a thousand million metric tons of sediment to the oceans in one year. Increase this figure by the additional amount of sediment transported by the other large rivers of the world and multiply it by hundreds of millions of years. You would then have some idea of the staggering quantities of sands and muds involved.

Since mountains, including those derived from former sedimentary deposits, are themselves an important source of such material, it is not surprising that the supply of sediment appears to be almost limitless. Even today, the rocks of the Appalachian region are estimated to be still several kilometers thick in places. The ultimate origin of this sedimentary rock is the apparently inexhaustible reservoir of the earth's interior, which from time to time emits vast quantities of molten rock. The latter then solidifies and is later eroded.

Fold mountains themselves, however, do not give a real inkling of the tremendous masses of sediment that went into their creation. When sediments become rock, there is great shrinkage in their volume. Later these rocks are folded and compressed into a still smaller space. Remember, also, that even existing mountains have undergone considerable erosion.

Geologists have attempted to reconstruct the original extent of the deposits making up some of the major mountain systems of the world. In extreme cases, the folding and faulting alone represent a measurable shortening of the earth's crust. Yet even today we come upon ancient rocks that have scarcely been disturbed, proving that much sediment has never been involved in orogenic processes. This reveals the superabundance of sediment available for geologic activities.

UPARCHINGS AND DOWN FOLDINGS

Not only have mountains originated from the bottom of vanished seas, but they have often been submerged long after their formation, and then re-elevated. The record

of their submergence may be read in the deposits that settled on them while they were under water. These later deposits may lie at various angles to the original bedding of the mountains, since they were formed on slopes and ridges.

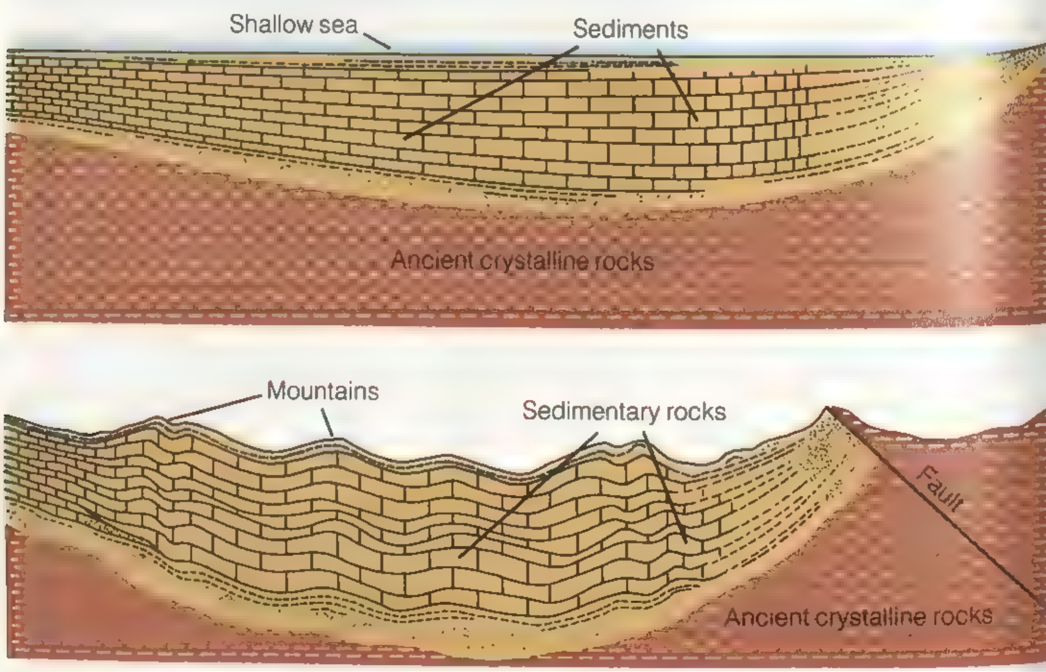
How can we explain or understand the powerful forces that folded and raised gigantic masses of rock into mountain ranges? Geologists have offered various theoretical explanations, some of which we shall discuss later in the article. Orogenic forces act very slowly and imperceptibly over long ages of geologic time.

Originally, when layers of sediment were deposited on the bottom of the sea, they must have been primarily flat and horizontal. However, if we examine major mountain systems, such as the Appalachians, the Rockies, or the Andes, we find that the *strata*, or layers, making them up are often not really horizontal. The layers have frequently been crumpled into a series of folds. These folds are in the form of crests and troughs resembling vast ocean waves. The crests, or arches, of the folds are called *anticlines*. The troughs, or downfolds, are known as *synclines*.

A syncline is much smaller than a *geosyncline*. The latter is a vast downarching of the earth's crust stretching for hundreds or even thousands of kilometers along the axis of the fold. On the other hand, a syncline may measure only one meter in width (although it may be much greater in length). A geosyncline may contain hundreds of synclines and anticlines.

There are also vast uparchings of rocks called *geanticlines*. A geanticline may lie parallel to a geosyncline and provide sedi-

Simplified cross sections of a geosyncline, or trough, of sediments (top), and of a mountain range later formed from it (bottom). Width of geosyncline and of mountains is measured from left to right, length, or axis, of geosyncline and of range is measured at right angles to the page (here indeterminate). Vertical scale is greatly exaggerated. In the geosyncline, the brick pattern stands for lime deposits; in the mountains, for limestone. The dashed pattern represents mud in the geosyncline and mud rock (shale) in the mountains. The dotted pattern indicates sand in the geosyncline, sandstone in the mountains. The sources of these sediments and rocks are landmasses to the right and left of the geosyncline.



ments for it. Like a geosyncline a geanticline may also be formed of many smaller anticlines and synclines.

FAULTS

Geosynclinal beds are often broken or cracked as well. Should the rocks on both sides of a crack be displaced in relation to each other, the crack is called a *fault.* Gigantic faults may extend for several hundred or thousand kilometers. They represent zones where huge rock masses have perhaps been displaced or shoved for as many kilometers. Sudden rock movements along faults often cause severe earthquakes.

Folds and faults are evidence of tremendous earth forces that work or once worked on the rocks in a geosyncline, forming them into mountains. Forces may have been powerful enough to overturn some of the rock beds. In many cases, sediments and the sedimentary rocks that were formed from them have been greatly changed, compressed, and shortened by vast forces.

These forces acted, not so much in the up-and-down direction, but in other directions. The earth movements were of such a nature as to show that horizontal forces acted parallel to the rock beds. However, vertical forces have been responsible for a certain amount of folding and uplifting.

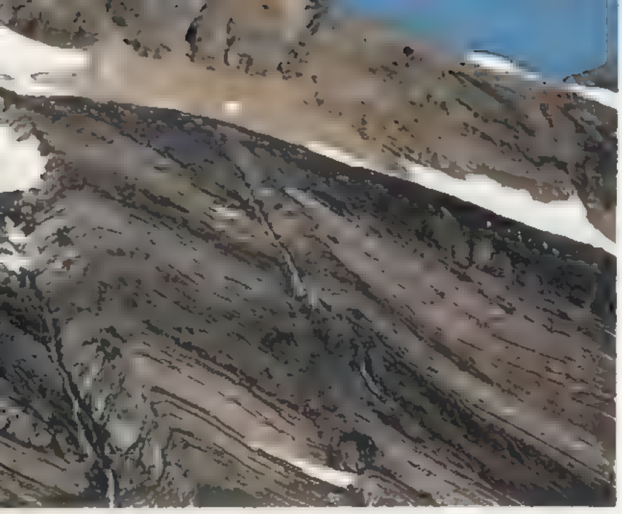
THEORIES OF MOUNTAIN-MAKING

A once commonly accepted explanation for the origin of folded mountains was the *contraction hypothesis.* It held that the earth has been shrinking steadily, either because of the enormous pressure of the overlying rocks or because of progressive cooling from a formerly hot or even molten state. The shrinking of the earth would cause the crust to wrinkle all over. The wrinkles are the valleys and mountains, suggesting the folds caused in the skin of an apple that has been drying and contracting for some time.

At the start of the twentieth century, the English astronomer George H. Darwin presented another explanation for the for-

The layers of this rock have formed into a series of folds resembling those of large ocean waves, with clearly visible crests and downfolds. This is an example of the types of formations known as syncline and anticline.

Jerome Wyckoff



Steve Coombs, Photo Researchers

As rocks are subjected to pressure by adjacent landmasses, they buckle and fold. Above: a folded ridge in Glacier National Park.

mation of mountains. He held that the earth was originally more flattened out at the poles than it is now. When it became more spherical, the bulge at the equator contracted. This resulted in lateral (sidewise) pressures that have generated folded mountains in an east-west direction. Darwin accounted for the existence of north-south ranges as due to the effect of lunar tides on the earth's rotation. The combined forces would produce folds in the earth's crust in positions at right angles to the direction of greater pressure.

"In the case of the earth," he wrote, "the wrinkles would run north and south at the equator . . . Any wrinkle when once formed would have a tendency to turn slightly so as to become more nearly east and west than when it was first made."

This theory has few supporters at the present time. The tremendous forces that Darwin mentions could have acted effectively only in the youth of the world, before the formation of the world's mountain chains. Besides, the Darwin theory does not account for the evident relationship between sediments and mountains.

Millions of years of sedimentation preceded the emergence of the Alps and the Carpathian Mountains of Europe from the sea. The same sequence of sedimentation followed by uplifting is evident in the mountain ranges of the North American continent. The U.S. geologist James Dwight Dana observed that "the region over which sedimentary formations were in progress in order to make finally the Appalachian range reached from New York to Alabama, and had a breadth of 100 to 200 miles [150 to 300 kilometers] . . . The pile of horizontal beds along the middle was 40,000 feet [12,000 meters] in depth. The pile for the Wasatch Mountains was 60,000 feet [18,000 meters] thick . . . The beds for the Appalachians were not laid down in a deep ocean, but in shallow waters, where gradual subsidence was in progress; and they at last, when ready for genesis [that is, for the actual mountain-raising process] lay in a trough 40,000 feet [12,000 meters] deep, filling the trough from brim to brim." The Laramie range, which extends from southeastern Wyoming into Colorado, is a spur of the Rocky Mountain system. It was reared from sediment 15,000 meters deep.

BABBAGE'S HYPOTHESIS

Whatever, then, the explanation of mountain chains may be, it has to account for their sedimentary beginnings. Various theories have been advanced to explain how mountains have arisen from sedimentary formations. An English geologist called Babbage offered an explanation that won considerable favor at one time. According to Babbage, the heaping up of sediment on the ocean floor must cause a rise in the temperature of the former floor, since the temperature of the earth increases with depth. A 300-meter deposit of sediment on the ocean bottom would cause the area that it covered to rise to about $-7°$ Celsius. At the same time, the erosion of land surfaces by wind, running water, weathering, and other factors would cause a lowering of temperature in other areas below the earth's surface, since they would not lie so deep as before.

Babbage held that the uneven heating of adjacent areas accounted for the formation of mountain systems. The areas where temperature had been raised as a result of sedimentation would become weakened and would be affected more than before by the lateral (sidewise) pressure exerted by

the adjacent layers, whose temperatures would be lowered. Hence the pressure would cause the heated areas to be forced upward.

The English geologist T. Mellard Reade proposed a modification of Babbage's theory. He suggested that the sediment plastered on the floor of the sea would act like a strip of nonconducting material on the surface of a cooling ball of metal. It would retain and raise the heat of the part of the earth's surface that would be covered. In time, this sedimentary strip would be heated itself above the average temperature of the crust. The excess of heat would cause the sediment and the underlying rock to expand. Expansion laterally or downward would be restricted. Hence the affected area would be forced upward, "as a cake expands upward on being baked."

ROLE OF RADIOACTIVITY?

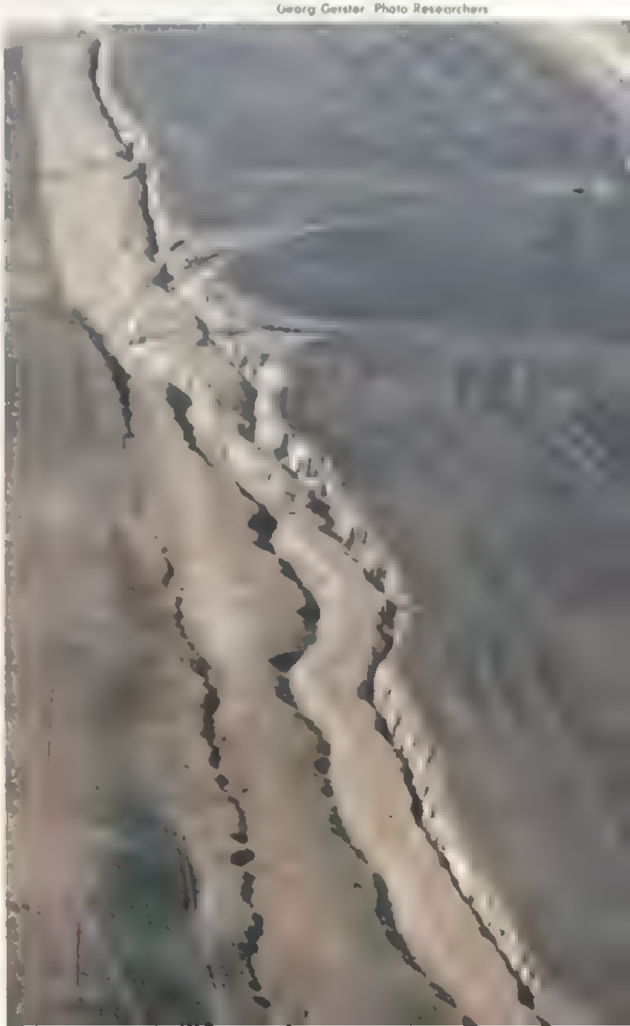
Another geologist, John Joly, held that radioactive materials, accumulating in the earth's crust, brought about a rise in temperature that weakened the earth's crust in many places and caused the buckling that has brought about the formation of mountains. "Given a local source of heat [radioactivity] applied above, while the normal heat of the earth flows upward from beneath, and the area where these conditions exist must necessarily become the first place of yielding and flexure, as naturally as the rupture of the chain occurs at the weakest link."

ISOSTASY

It was quite generally held at one time that mountain building was due to *isostasy* (from two Greek words meaning "equal stability"). Isostasy is still a valid concept insofar as it refers to the maintaining of equilibrium in the earth's crust. This is brought about as large-scale earth movements in one area are counteracted by compensating movements in other areas. According to the concept of isostasy, segments, or blocks, of the outermost shell of our planet are more or less in balance with each other and weigh about the same. Uplands and mountains are underlain by rocks of a density less than that of the rocks beneath lowlands and the ocean bottom. The mountains and plains may be said to "float" in a layer of still denser rock under them. This deep layer has been compared to a liquid, although it is actually a plastic solid that "flows," or deforms, very slowly under high pressures.

The uplands resemble icebergs and the lowlands, ice floes, floating in water that is denser than they are. True, a berg in itself is larger and heavier than a floe. The former, therefore, floats deeper and has a large "root" of ice projecting down into the water and displacing it. The iceberg thus is sup-

Georg Gerster Photo Researchers



In many mountainous areas strong horizontal earth movements take place. In such areas cracks, or faults, often occur. Part of the spectacular San Andreas Fault in California is seen at right

ported by a "column" of water much shorter than the one holding up the ice floe.

In the earth's crust, isostatic adjustment by deep rock flow is a response to nonisostatic forces causing unbalance and strain in other rocks.

The older theory of the formation of mountains through isostasy was as follows. A sea bottom would be filling with sediments eroded from an adjacent mountain tract. As they would accumulate and press on the bottom, the latter would be downwarped into a trough, which would reach the crustal substratum, or *flow zone*. The substratum rocks would move toward the mountains, to compensate for the sinking trough and for the lightening of the mountains by erosion. The latter would rise, but less so with each successive uplift. There would be a limit as to how far the geosyncline would descend, also, and so the subcrustal flow would slacken. The transfer of vast amounts of sediment across the earth's surface was considered one of the prime movers in the building of mountains. This transfer plus the isostatic responses to it were supposed to have produced mountain ranges.

When sediment, the raw material of mountain building, becomes uniformly tilted, the result is a formation called a hogback, as seen below.

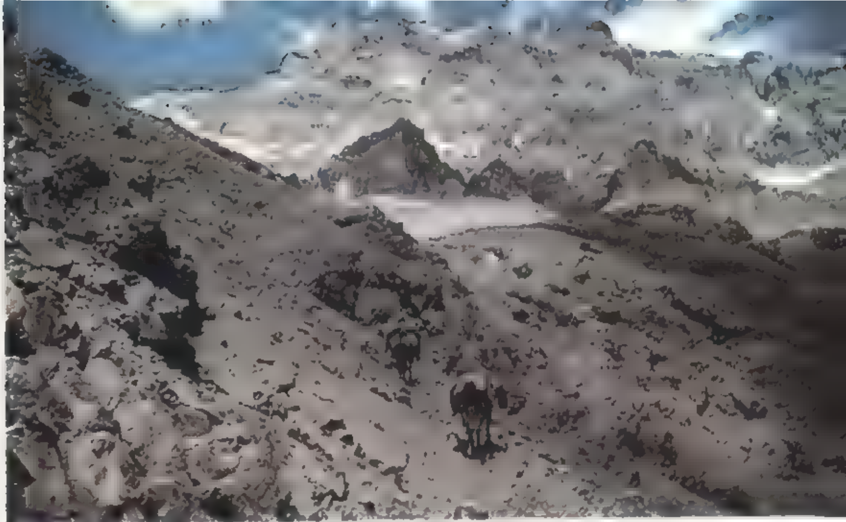
Jerome Wyckoff

Isostasy is considered today as inadequate either to develop geosynclines or to cause orogeny. For example, certain very deep trenches in the ocean floor are underlain by rocks less dense than those of nearby mountainous lands. Obviously these rocks, here not supporting heavy loads of sediment as yet, were not pushed down so far by isostatic movements. Other forces, whose nature is still in dispute, must have been responsible for this situation.

Isostasy may, however, trigger off mountain-building forces. As the rocks of the geosyncline sink into the flow zone, the heat in this region softens and weakens them. The stronger rocks surrounding the geosynclinal layers at a somewhat higher level then fold and fault the latter by lateral (sidewise) pressure. Many of these layers thus become thickened. Moreover, the lowermost ones are downfold farther into the zone of flow. These lower strata form a root of light material forcibly pushed downward into the denser part of the earth's crust. There is a limit as to how far this can go, however. Eventually the folded mass may tend to rise, or "float," higher. Also, continuing horizontal pressures may at last force the crumpled beds to "ride" or be bowed upward against or over the more resistant rocks around them. Molten rock material rising through the sedimentary layers probably helps raise them also.

CONTINENTAL-DRIFT THEORY

The theory of *continental drift*, once quite discredited, has now gained wide acceptance. According to this theory, vast landmasses have shifted horizontally for long distances. In so doing, they have collided with other landmasses, causing the uplift of the earth's crust at the scene of the collision. The theory holds, for example, that the Alps and the other mountains of southern Europe were formed as the African continent moved northward and met the landmass to the north. The Rocky Mountains in North America and the Andes in South America resulted from the westward movement of the two Americas.



Cerro Aconcagua, the highest mountain in the Western Hemisphere. The effects of erosion are evident in the fluted, carved appearance of [illegible]

Mario Fantin, Photo Researchers

The mountain chains of southern Asia were raised as the Asian continent drifted southward.

Supporters of the continental-drift theory point out that the outlines of the western coasts of the Eastern Hemisphere continents seem to match the eastern coasts of the Western Hemisphere continents. This suggests that these regions once formed a single landmass. The strata and fossils of certain geological periods in the now separated continents show striking similarities, and this would seem to bolster the idea of continental drift. There is evidence, too, that in past times the earth's magnetic poles were located in positions far distant from those of today.

The older continental-drift theorists held that the continents floated freely in a universal substratum of plastic or near-liquid rock. Later, other scientists maintained that currents, arising from the earth's heated interior, moved the crustal landmasses around. This would disrupt them and crumple their strata, resulting in the formation of mountains.

According to the opponents of the continental-drift theory, the evidence provided by the earth's rock strata and fossils points to thousands of millions of years of orderly continental development. This would have been impossible if the landmasses had moved about. Then too, some evidence seems to indicate that the foundations of the continents reach very far down into the earth. This would make the concept of moving continents hard to accept, according to antidrift geologists. They believe that much of the so-called "evidence" for continental drift can be explained otherwise.

EROSION OF MOUNTAIN RANGES

As soon as newly born mountains arose, the eroding effects of air and water began to carve them into peaks, now not half so high as they were originally. Wind and rain, frost, ice, and snow, and the mighty force of running water have been diligently at work for millions upon millions of years, and the wear and tear have been tremendous: 4,500 to 6,000 meters have been removed from the ancient mountains of Wales. From the mountains in the Lake District of England and from part of the Appalachian range in the eastern part of the United States over 7,600 meters—a little less than eight kilometers have been worn away. At one time there was a sedimentary layer 15,000 to 18,000 meters deep above what is now the Simplon, an Alpine pass reaching an altitude of about 2,000 meters. The Laramie range in the Rocky Mountains would average 10,000 meters high today if it had not been eroded.

AT VARYING RATES

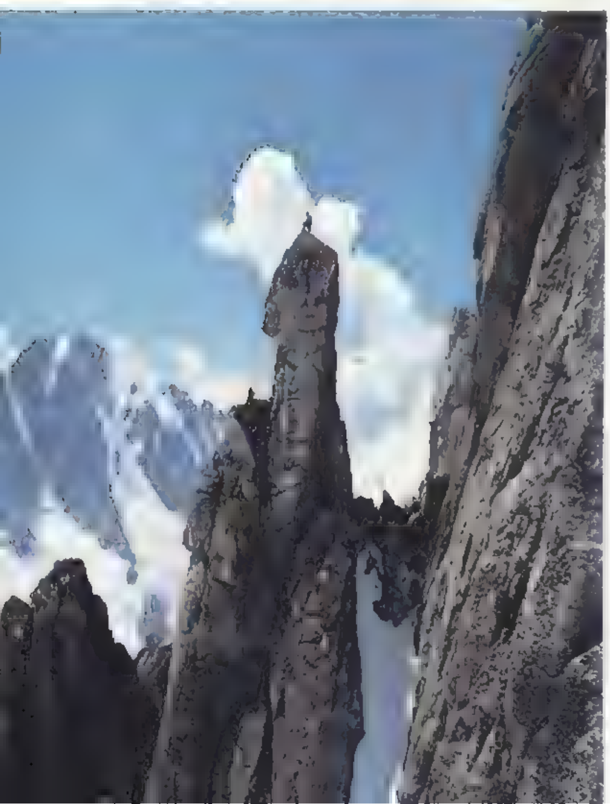
It is interesting to note that the original ridges, or anticlines, wear away much faster than the troughs, or valleys, or synclines. The reason seems to be that anticlines are more exposed to erosive forces.

Anticlines are eroded so much more rapidly than synclines that in some cases the original relationship between these two

types of folding has been reversed. The syncline has now become the mountain crest, and the anticline has become the valley. This reversal has taken place in the Appalachian Mountains, for example. The mountain summits of this range were originally synclines, the valleys anticlines.

The rate of wearing away of mountains and the shape to which they are worn depends on various factors. One of these is the direction followed by the strata that compose them. Another is the material of which they are composed. Limestone is worn away quite rapidly and it generally assumes a curved pattern. In certain instances, it may take the shape "of ruined masonry, suggesting crumbling battlements and tottering turrets." Although granite resists the action of the elements longer than limestone, it, also, is subject to erosion and is often worn into huge square blocks. Granite mountains rarely have sharp peaks. They are usually rounded and massive like Pikes Peak, the crown of which is naked granite. The lofty, jagged peaks of the European Alps, which constantly challenge the skill and courage of the mountain climber, are composed of gneiss and mica schist, hard crystalline rocks. These high, barren elevations are of more recent formation than the mountain chains of low rounded tops and uniform slopes like the Adirondacks.

The pinnacles on Mont Blanc, France's highest mountain, are examples of igneous rock formations, stripped and weathered over millions of years.
P. Tairraz

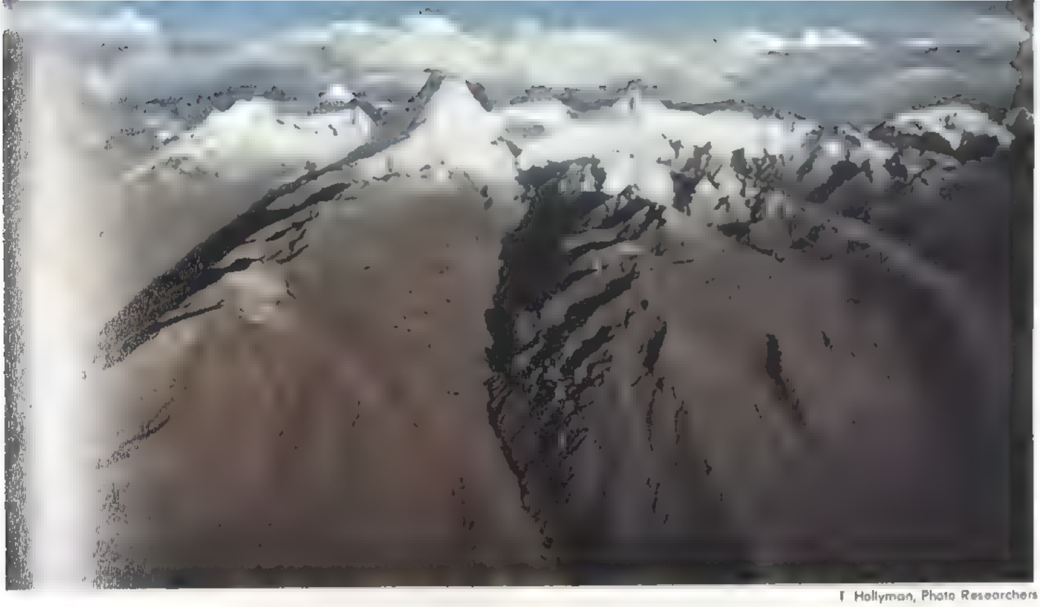


The snow-covered crests of the Hindu Kush Mountains in central Asia, rising more than 7,000 meters above sea level in places, are of more recent origin than the more graduated Himalayas. Although a single peak of the Himalayas, Mount Everest, towers nearly 9,000 meters above sea level and is the grandest of all mountain tops, the Himalayan range is for the most part considerably lower than Everest.

The average height along the central axial line of the Himalayan peaks is not more than 6,000 meters above sea level. This mountain range is the result of a very long series of upheavals and depressions with a geological record going back to Precambrian times in the oldest beds. In this most ancient process the sharp upthrusting of Mount Everest is of comparatively recent origin.

This illustrates that within the history of a particular mountain chain the rate of uprising may vary considerably. Thus in the Himalayas there exist three plainly defined periods of development, beginning in the north and working south. It is probable that the initial process was a violent crumpling of the earth's crust along the southern margin of the great tableland of central Asia. The gradual character of subsequent changes is indicated by the undeviating courses of the Indus and Brahmaputra rivers, cutting deep gorges through the mountains.

Changes taking place in any given area may ultimately result in widespread effects over the whole mountain range. Thus the process of *denudation*—the stripping and weathering of mountain peaks by the elements—may be compensated by a gradual rise in the base elevation through faulting and folding of the earth's crust. The geologists who favor the theory of isostasy



T. Hollyman, Photo Researchers

According to the theory of continental drift, these mountains, the Andes in Peru, were formed when the great landmasses shifted.

(which, as we saw previously, emphasizes the isostatic balance of forces) maintain that the effects of denudation are offset by the elevation of the base. In Sweden, for instance, much of the land is gradually rising out of the sea. In some districts the pine forests of mountainous slopes have been elevated beyond the timber line into regions of perpetual snow, where the trees have been killed by the cold. The coasts of Scotland are notable for their rock terraces, rising one above the other to a height of more than 20 meters from the sea.

This increase in base elevation is often accompanied by the intrusion of great *batholiths*, igneous rocks with a toughening core of granite, into the lower part of the mountain. Unlike extrusive rock, intrusive masses of igneous rock are prevented from reaching the surface of the earth but may act as a massive lever to elevate the surface strata. It is possible, however, that an intrusive mass lying near the surface may be in time uncovered by the action of the elements.

INTERIOR HEAT AT WORK

Igneous rock is, as its name implies, molten rock from the interior of the earth. The earth's interior heat is constantly exercising a pressure against the upper strata of rock, creating folds and faults in the crust through which the igneous rock pushes. The original molten rock is cooled and solidified in the process of reaching the upper layers. It distributes itself in various forms such as the gold-bearing saddle reefs of South Australia or the domes and cupolas that are to be found in the tin regions of western Cornwall.

ESTIMATING MOUNTAIN AGE

In estimating the relative age of the mountains and the varying periods of their formation, certain standards are employed by the geologist. Marine fossils have already been mentioned, and these are useful within definite limits. It seems evident, however, that the very extreme antiquity of the earth is hardly encompassed by the available marine fossils. These fossils are highly complex forms that resulted from a long evolutionary process and were not present at the earth's beginnings.

To supplement the fossils, the evidence of radioactive elements in the rocks of the earth is called on. All radioactive minerals found in rocks are a form of geologist's clock. There is a constant measurable rate of disintegration of the radioactive element that determines within close limits the age of the rocks. This wonderful self-operating clock reveals the earth to be several thousand million years old.

PLAINS, PLATEAUS, AND DESERTS

Among the most striking regions of the world are its plains, plateaus, and deserts—large tracts of comparatively flat land. They range in height from plains depressed below sea level to lofty plateaus, or tablelands, lying at elevations of 4,500 meters or more. There is no sharp distinction between plateaus and plains. In general the term *plain* is applied to relatively flat regions less than 300 meters above sea level; the term *plateau*, or *tableland*, to similar stretches of land more than 300 meters above sea level. However, what makes a flat expanse of country a plain or a plateau is not necessarily its absolute height but its elevation compared with that of the surrounding area.

The word *desert* is loosely applied to dry, or arid, and semiarid plains and plateaus. Many so-called "deserts" are not true deserts at all, because they receive at least a few centimeters of rain annually at certain seasons and thus support some vegetation. The Kalahari Desert of Africa is an example. It is a semidesert. Many [illegible] deserts, such as the Sahara in Afric[illegible] the Arabian Desert in Asia, may recei[illegible] rain at all, and be entirely lacking in [illegible]tion.

VARIED CLIMATES

The climatic conditions of [illegible] and plateaus are rather varied. Dep[illegible] on their latitude, location, and ele[illegible] they range from hot to cold and from [illegible] to humid. Many plateaus are cold an[illegible], no matter what their location, becau[illegible] their elevation. This is the case with t[illegible]teau of Tibet and the Altiplano of Boli[illegible] Aridity on plains and plateaus is due t[illegible]riety of factors. They include nearnes[illegible] high mountain ranges, heat, and adve[illegible] ocean currents. Certain coastal plains[illegible]ch as those along the shores of Chile [illegible] Peru, are really deserts. On the other h[illegible] lowlands far from the ocean may be [illegible]umid as to support huge areas of den[illegible]ungle. The Amazon Basin of Brazil is th[illegible] chief

example here. Some areas, just humid enough to allow the growth of grasses, such as the pampas of Argentina, the steppes of the Soviet Union, and the Great Plains of the United States, are important grazing and agricultural regions.

ORIGINS

Plains and plateaus are brought into existence by a variety of geologic processes. One very important factor is erosion by wind and water—the wearing down of land surfaces, even lofty mountains, to featureless or almost featureless expanses. Such a plain or near plain—called a *peneplain*—may then be elevated by earth forces to form a plateau. The latter, of course, is attacked by erosion and is progressively lowered, unless it is re-elevated. If the rocks composing the plateau vary in hardness and position, they are etched out to form hills and mountains. A number of mountain masses in the world today are the remnants of once extensive plateaus. This is true, for example, of the Catskill Mountains in New York State.

Sovfoto

Tundras are low, cold-area, desolate plains. Here some elk running across the barren snow-covered tundra of the northern Soviet Union.

The Gobi is the largest desert in Asia. Here a camel caravan approaches one of the few small lakes found in the area.

Eastfoto

Coastal plains—lowlands fringing the edges of some continents, especially North America and Europe—are usually adjacent sections of the sea floor that have been uplifted in recent geologic times and are now part of the land. Their flatness reflects the normally level beds of sediment that compose them and the erosive effect of the ocean waves. So-called *alluvial plains* consist of sediments deposited by rivers on land. *Delta plains*, such as those of the Nile, develop on vast deposits left by great rivers at their mouths. An exceptionally broad and level river valley is often referred to as a plain. *Lake plains* occur on beds of mud or rock left by long-vanished lakes. Thus we see that any number of climatic and geologic agencies may cooperate to produce plains, plateaus, and deserts.

The flat lands of the earth's crust may range from only a few square kilometers in area to several million square kilometers. The greater the area, the more likely it is to depart from the conventional idea of a prevailingly flat or level expanse. For example, the vast Sahara, though generally level or rolling, has towering mountain ranges and sand dunes at its very heart.

PLAINS

The largest plain in the world is that of Eurasia, which stretches across the north of

The name "piedmont" has come to stand for a plateau of the Piedmont Plateau type—one between a low-lying area and a mountainous area. A typical piedmont profile is shown below. The photo at right shows rich farmland of the area.

Hammond Inc

Max Th... pe ... ociates

Hammond Inc

Spa[illegible] Office

The central plateau of Spain typifies plateaus that rise more or le[illegible] bruptly from the sea or from a narrow coastal plain. Above left: a profile of [illegible] tableland. Above right: a typical landscape of the Spanish tableland

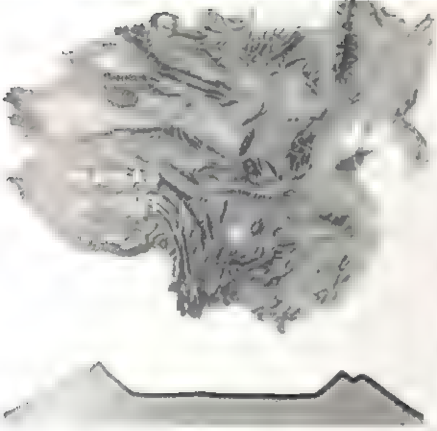
Europe and Asia from the North Sea to the east of Siberia. This immense expanse is divided into an eastern and a western half by the Ural Mountains.

Another great plain is the Amazon Basin, which presents the gentlest land slope in the world. Yet another runs down the center of South America, bordering the base of the Andes and including one fifth of the continent.

Landes. Some European plains are called landes. The landes of southwestern France are marshy plains in the departments of Landes, La Gironde, and Lot-et-Garonne. They are of submarine origin and are so marshy that shepherds in the area use stilts to herd their flocks. The French landes originally covered over 800,000 hectares. Much of this has now been reclaimed.

Even more extensive are the landes in Holland and the north of Germany. In Holland there are 1,000,000 or more hectares, covered with spongy peat mosses.

Steppes. In Hungary and in the central part of the Soviet Union, instead of landes, we have the plains known as steppes. In Hungary, they are simply prairies of natural grass and meadow flowers, over which roam herds of oxen and horses. In central Russia, the steppes are enormous: the Tchernozom steppes alone extend about 80,000,000 hectares. The greater part of this area is simply grass, but much of it is under corn. The soil is rich and hardly to be surpassed for growing corn. South of the Tchernozom



Hammond Inc

Eastfoto

The ...ateau of Tibet typifies the third type of plateau – that ringed by mountains Abo... left: a profile of such a plateau. Above right: a photo of the Lhasa plain, whic... is a part of the Tibet plateau.

s... in the neighborhood of the Caspian Se... ere are barren steppes of white sand a... dish clay where only a few shrubs w... w. For a straight-line distance of 5... meters only one kind of a tree – a sp... of poplar – is to be found.

...dras. The low plains found in the n... the Soviet Union are known as tu... They are some of the most desola... cts of country in the world. In the w... they are covered with snow. In su..., they are converted into a boggy la... overed thickly with reindeer moss and whitish lichen.

...airies. A large, almost treeless tract of the Mississippi Valley is known as the *p... region.* Its eastern border is an irre... forest line running southeast through M...sota and Wisconsin into western In...a, there turning southwest through Illinois and Missouri to the borders of Oklahoma and eastern Texas. From this line the prairies stretch westward 300 to 950 kilometers, merging into the Great Plains. They are now one of the greatest grazing and farming regions in the United States.

Pampas and llanos. In South America, in the basins of the Amazon and other large rivers, there are plains checkered with forests and grasslands like the Mississippi basin plains. There are also tracts of unbroken grass. In South America, the grassy plains are known as *pampas* and *llanos.* In the warmer zones, mimosas and other shrubs grow among the grass. The llanos of Venezuela and Columbia are remarkable for the manner in which they are alternately desert and pasture-land. Before the rainy season, the soil is dried up and all vegetation perishes, and the llanos become a veritable desert. Then all at once the storms of the rainy season inundate the soil. Multitudes of plants shoot from out the dust, and the immense yellow expanse is transformed into a flowery meadow. The most remarkable plains in South America are the Argentine pampas, which stretch for a distance of more than 1,500 kilometers between Brazil and Patagonia. These extensive plains are probably the most important grazing grounds in the world.

PLATEAUS

Plateaus may be divided into three different classes. Some of them, like America's Piedmont Plateau, separate a low-lying plain from a mountainous area. Others, like the plateau of Tibet, are ringed by mountains. Still others, like the central plateau of Spain, rise more or less abruptly from the sea or from narrow coastal plains.

The United States has a number of plateaus belonging to the first and second of these classes. The Piedmont Plateau lies west of the Atlantic coastal plain and east of the Appalachian Mountains. It stretches from New Jersey to Alabama, reaching a width of nearly 500 kilometers in North Carolina. The Colorado Plateau spreads for 330,000 square kilometers over parts of Arizona, Utah, Colorado, and New Mexico. It is dissected by a number of deep canyons, including the huge Grand Canyon. In the northwestern part of the country, the Columbia Plateau, lying in Oregon, Wash-

ington, and Idaho, is an extensive tract measuring some 250,000 square kilometers. Much of it was built up of successive lava flows.

Certain plateaus, like those of Tibet and the Pamir in Asia are among the most forbidding areas in the world. Others, like that of Uganda, have an invigorating climate, often in marked contrast with that of the surrounding regions. In the Americas, the civilizations of the Aztecs, Toltecs, and Incas were concentrated on high plateaus. And today many large cities are found there.

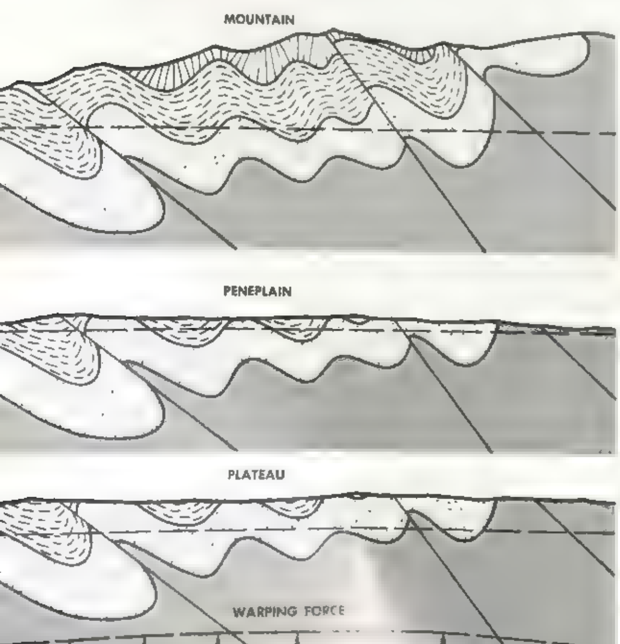
The vast plateaus that lie in the vicinity of the Himalaya mountain system of Asia serve to "bring down the north into the very bosom of the south, and to unite within a limited space all the climates of the year." The loftiest of these plateaus is that of Tibet, with an average height of 4,500 meters. It is hemmed in by the mighty Himalayas in the south and the Kunlun Mountains in the north. Another great tableland is that of the Pamir, which is called by the natives the "Roof of the World." It lies at an altitude of from 3,500 to 4,000 meters above sea level. The Plateau of Iran extends for a distance of something like 2,500,000 square kilometers over parts of Iran, Afghanistan, and Baluchistan. The average altitude of this plateau is from 900 to 1,500 meters.

In Europe, there are no plateaus to compare in height with those of Tibet or the Pamir. More than half of Spain is made up of a tableland, called the Meseta, with an average height of 600 meters. A large part of Bavaria, in Germany, is plateau country, averaging about 500 meters above sea level.

The continent of Africa, second in size only to Asia, is made up very largely of plateaus with an average height of 600 meters above sea level. A band of high plateaus runs from the Red Sea southward and westward for thousands of kilometers. While most of the continent is tableland, there are also high mountain ranges, the vast Sahara, the low-lying Nile Valley, and the coastal regions.

An interesting South American plateau is the Altiplano, situated mainly in Bolivia between two ranges of the Andes Mountains. About 3,600 meters high, 725 kilometers long, and 130 kilometers wide, the Altiplano is one of the most thickly settled of the world's high regions. This extensive tableland is so shut in by mountains that all its rainwater is retained in its own basin and drains into its own lakes.

Three steps in the formation of one kind of plateau. Top: mountains are formed as the result of folding and faulting. Middle: erosion gradually wears down the mountains to a peneplain. Bottom: warping causes the peneplain to be elevated and results in the formation of a plateau. The plateau will be attacked by erosion and will gradually be lowered, unless it is reelevated by natural forces. If the rocks that make up the plateau vary in hardness they will be etched out in the course of time to form hills and mountains.



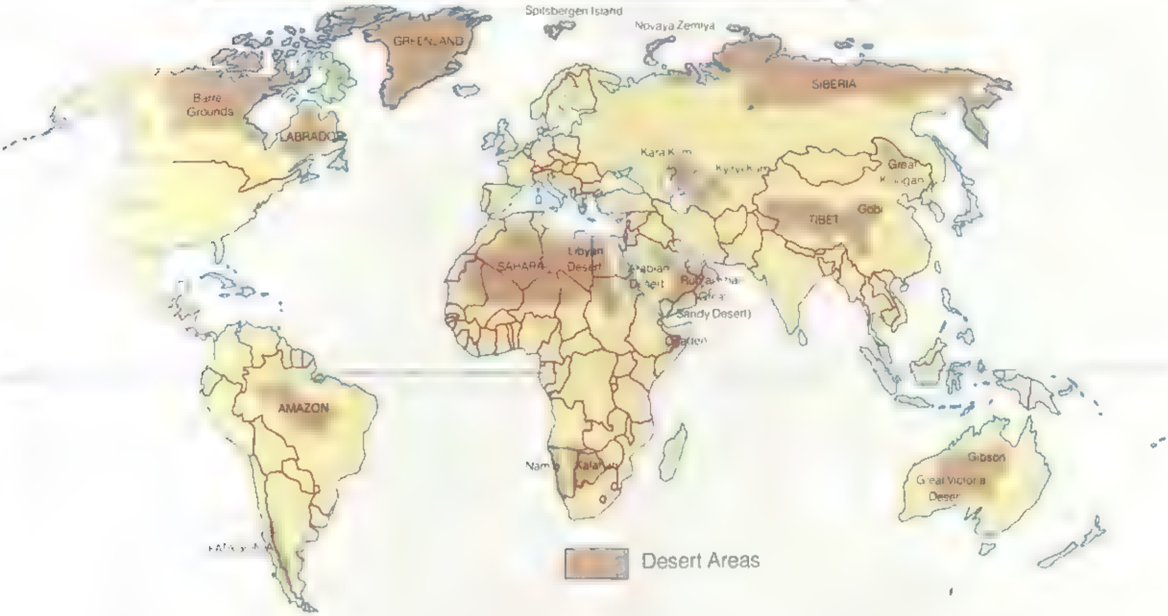
DESERTS

Besides landes, tundras, prairies, llanos and steppes, there are the great deserts, properly so called, which are sometimes plains and sometimes plateaus.

THE SAHARA

The best-known desert plain and perhaps the most typical desert is the Sahara, which extends across Africa from the Atlantic to the Red Sea, a distance of some 5,000 kilometers. The breadth of this desert zone averages more than 1,700 kilometers, and altogether the desert covers an area as

MAP SHOWING THE MAIN DESERTS OF THE WORLD



large as the whole of the continent of Europe. Its mean height is 450 meters. It might, therefore, be considered a plateau rather than a plain except for the fact that there is no low ground to contrast with the general level of the sands. Strange through it may seem, only about an eighth of the Sahara's surface is made up of sand. Most of it is soil and rock.

A group of lofty mountains, extending along the middle of the Sahara from north to south, divides it into eastern and western portions. The western part is a wilderness of sand blown by the winds. Toward the west the sand is carried into the ocean. Toward the south it moves into the Niger and Senegal rivers, in such amounts as gradually to alter their courses. The eastern Sahara is also a tract of sand, but numerous plateaus of rock and clay and a fair number of mountains break the monotony of the plains.

The Sahara is so hot and dry that it is almost uninhabitable in far the greater part of its extent. The lack of water is fatal to most forms of life. The only creatures that abound in the desert are scorpions, lizards, vipers, and ants.

The Sahara is subject to great extremes of temperature. Readings as high as 58° Celsius have been recorded. In the cool season, however, the mercury may drop to 4° Celsius or so. There may be frost, particularly in the western areas and in the highlands of the central regions. In summer, the relative humidity may fall to the extraordinarily low mark of five per cent, even in the vicinity of oases. In the cool season, it may reach 47 per cent. Even in the hot season, the temperature may drop thirty degrees and more at night. The air is so dry that heat radiates rapidly away from the sands that have been warmed by the sun during the day.

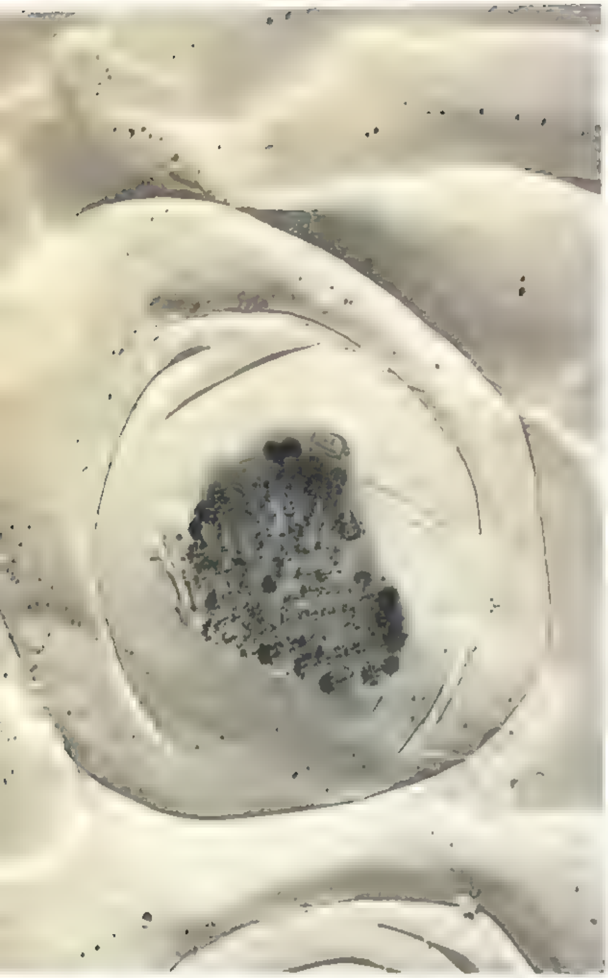
Wherever water rises from the earth or reaches the desert from the hills, an *oasis* – a little island of green – is created, standing out in startling contrast to the glaring sands of the surrounding desert. Oases are quite numerous in the Sahara. They are so located that in various regions they form a line across the desert, and it is possible to travel by stages for long distances. The desert soil is exceedingly fertile. It requires only water to make it blossom. Unfortunately, the supply of water to an oasis is not dependable. At times there is a severe drought. Occasionally, the streams that lead to the desert from the hills become raging floods, which may wash away the trees and the crops.

The most familiar plant of the oasis, of course, is the date palm, whose fruit – the date – provides a highly concentrated food. Sometimes dates are eaten as they are plucked from the tree; sometimes they are pounded and pressed into cakes. In the oases of the Sahara, apricots, peaches, pome-

granates, oranges, and various ot[illegible] fruits are abundant. Certain grain cro[illegible]ncluding corn, wheat, and barley, ma[illegible]rive in the oases, and clover flourishes u[illegible]r irrigation.

Much of the Sahara in south[illegible]nisia and northern Algeria is below se[illegible]el. In fact, it was once the site of a [illegible] which was called the Bay of Triton [illegible]ncient Greek writers. A volcanic e[illegible] cut this bay off from the Mediter[illegible]n. It eventually dried up in the fierc[illegible] leaving only a few scattered salt lak[illegible]e soil of this area is still potentially ve[illegible]le. If the Bay of Triton could be [illegible]d, it would open up the Sahara to int[illegible] agricultural production.

Various irrigation projects [illegible] been attempted in the Sahara. Wate[illegible] been obtained from artesian wells in ma[illegible]laces, particularly south of the Atlas ra[illegible] and in Algeria and Egypt. Despite th[illegible]forts, and despite the fact that there a[illegible]wn to be large reserves of subsurfa[illegible]ter—enough to render vast tracts fertil[illegible]ne Sahara is advancing southward at a[illegible]ming rate.



Gerster–Rapho

The Sahara is a vast desert with swe[illegible] plains broken up by plateaus and mountains [illegible] an oasis in the Algerian part of the Sahara. A[illegible] island of green, surrounding a small water suppl[illegible] stands out amidst the sands. Below: a sandst[illegible] in the Sahara, which is subject to extremes o[illegible]eather conditions.

Barge

ASIAN DESERTS

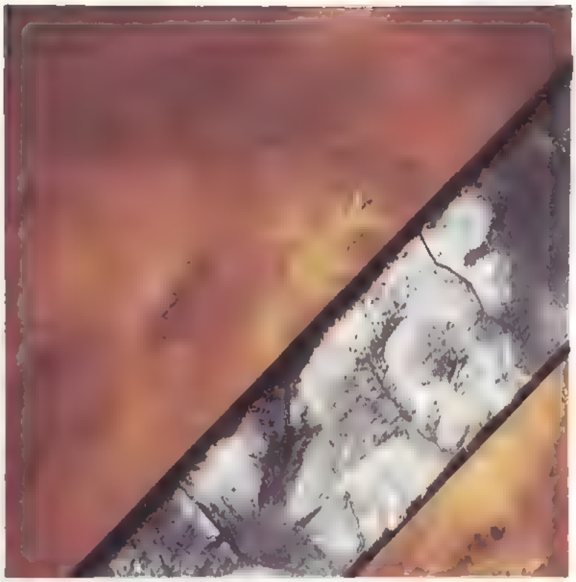
Across the Red Sea from the Sahara lie the deserts of Arabia. The Nafud, in the north, is a great belt of sand dunes, from 80 to 225 kilometers wide. These dunes are often very long and are separated by valleys that range up to 16 kilometers in width. In the east-central part of the Arabian peninsula is the desolate region known as the Dahna. It consists in the main of gravelly plains, covered at intervals with red sand. The sand peaks in this region sometimes rise to a height of 90 meters. The southern sand desert of Arabia, called Rub' al Khali, is a vast region 1,200 kilometers long by 640 kilometers wide, in which downs of hard sand alternate with areas of shifting, soft sands.

The largest desert in Asia is the Gobi, which in Chinese is called Han Hai ("dry sea") or Shamo ("sandy desert). The name "Gobi" is sometimes applied to the whole stretch of arid country extending from the Pamir to Manchuria and from the Altai and Sayan mountains to the Nan Shan, or southern mountains, of China. The Gobi proper is found in the eastern part of this vast region. It is a gravelly and sandy desert plateau which ranges in altitude from 900 to 1,500 meters. It is about 1,600 kilometers long by 800 kilometers wide.

Trees are almost unknown in this region. The vegetation consists chiefly of grass and shrubs. Water is found only in wells and small lakes. There are oases only on the shores of these lakes. Extremes of temperature in the Gobi are as startling as those in the Sahara. During the winter, when cold winds from the north ravage the land, the mercury sometimes drops to −50° Celsius. It reaches 45° Celsius in the shade during the summer months.

AMERICAN DESERTS

Perhaps the most striking desert area in North America is the Great Salt Lake Desert in northwestern Utah, a forbidding region of the Great American Desert. Extending some 180 kilometers south from the Grouse Creek Mountains, it consists principally of vast whitish gray plains,



NASA

A 50-kilometer-wide black-and-white radar scan of the Sahara, made by the Columbia shuttle in November 1981, is superimposed on a satellite image of the same area. The radar beam penetrated the surface sand deposits to reveal ancient river beds.

from which islandlike peaks and isolated ranges rise here and there. The floors of the plains are strewn with millions of metric tons of salt crystals. The salt deposits are so thick in places that they form a concretelike surface.

In South America, we find the Atacama Desert, famed for its nitrate deposits. This arid region, which lies in northern Chile, is bounded on the west by the Pacific coastal range and on the east by the Andes. It extends some 950 kilometers south from the Peruvian border. It is practically rainless and almost entirely barren. In the nineteenth century, however, men came to realize the value of its almost inexhaustible beds of nitrates. The Atacama Desert was the chief source of these valuable compounds until the development of synthetic nitrates.

AUSTRALIAN DESERTS

Much of the interior area of Australia, particularly toward the west, is made up of arid land. There is the Great Sandy Desert in the north and the Victoria Desert in the south. Livestock is raised in some sections. Other areas—the fixed dune lands—have never been settled. The dune sands in the uninhabited areas have been fixed by grass and bush and scrub growth.


Russ Kinne, Photo Researchers

Caves have had great significance in the course of human history. Markings on cave walls, the remains of simple tools, and other clues reveal that prehistoric families used caves such as this large one in Chile as their home.

CAVES

by Armin K. Lobeck

Caves have always had a great fascination for mankind, chiefly perhaps because of the mystery in which they are so often shrouded. As a cave explorer crawls through a narrow passageway, the rays of his lamp piercing the darkness ahead of him, he wonders what he will find around the next bend. Perhaps there will be an underground river, or a quiet pool, or a yawning pit. He may come upon an antechamber in which there are flowing draperies of stone, or a magnificent hall, adorned with natural sculpture that rivals the best that man can create.

In some caves one is able to lose all contact with reality. Go into a remote room of one of these caves, alone if possible. Extinguish all light, sit down, and wait. There is nothing to act upon your senses. You are in absolute darkness. There is not a sound, not the slightest movement of air. As the time passes, your body no longer seems to be a part of you.

In other caves the silence is broken by the sound of dripping water or of a gurgling stream. There may be a constant rush of air, as in the famous Wind Cave of South Dakota in the United States. You may

hear the whishing sound of bats that use the cave as their home. In the distance you may see a small shaft of light, proceeding from the entrance to the cave.

LIMESTONE FORMATIONS

The majority of the world's caves are to be found in limestone formations in many different parts of the world. Limestone is a sedimentary rock. It is made up mostly of calcium carbonate ($CaCO_3$), plus various impurities—that is to say, substances such as quartz, flint, or iron oxide. There may also be a considerable admixture of clay. Most limestone is the result of organic activity. It represents the remains of marine organisms, such as corals, mollusks, and various microscopic animals and plants.

Limestone formations, ranging in thickness from a few centimeters to many meters, are found in every one of the continents. In the United States, they occur principally in a belt running from New York to Alabama, in the central states of Ohio, Indiana, Kentucky, and Tennessee and in several western states. There are important limestone formations in various areas of Canada, including the Grenville region of southern Ontario, the Appalachian region, the St. Lawrence lowlands, and the Mackenzie River region.

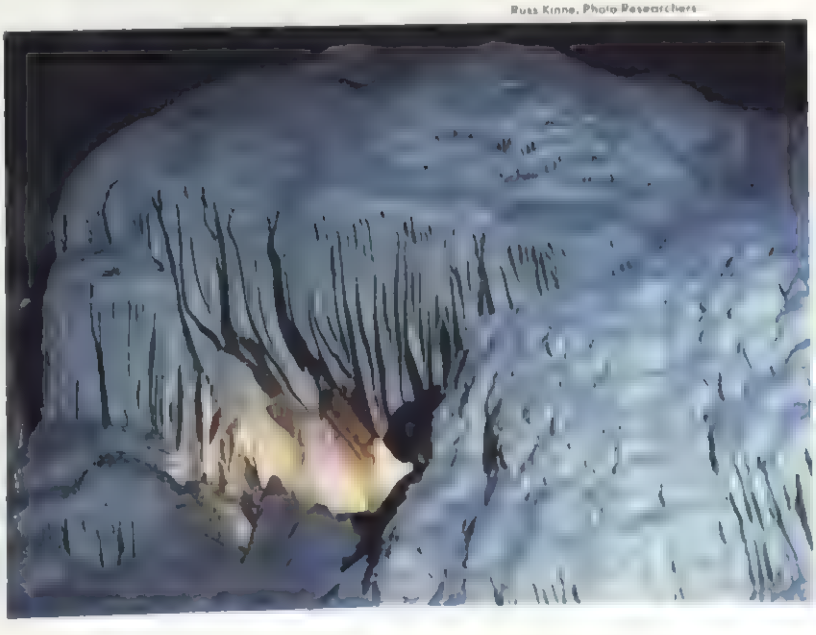
Calcium carbonate, of which limestone is chiefly composed, crystallizes in two forms—calcite and aragonite. These two crystals have different internal structures. Calcite is far more common than aragonite.

Calcium carbonate is soluble only in water that contains, dissolved within it, carbon dioxide gas (CO_2). This gas is to be found in practically all surface water. It is derived from the atmosphere. The chemical reaction that takes place when water containing carbon dioxide acts upon calcium carbonate is as follows:

H_2O	+ CO_2	+ $CaCO_3$	$\longrightarrow$	$Ca(HCO_3)_2$
water	carbon dioxide	calcium carbonate	yields	calcium bicarbonate

The calcium bicarbonate that is formed as a result of the reaction is very soluble and, therefore, readily removed by water. This explains why limestone is one of the weakest rocks in humid regions. In dry areas, such as the U.S. Grand Canyon, it is one of the more resistant formations.

Russ Kinne, Photo Researchers

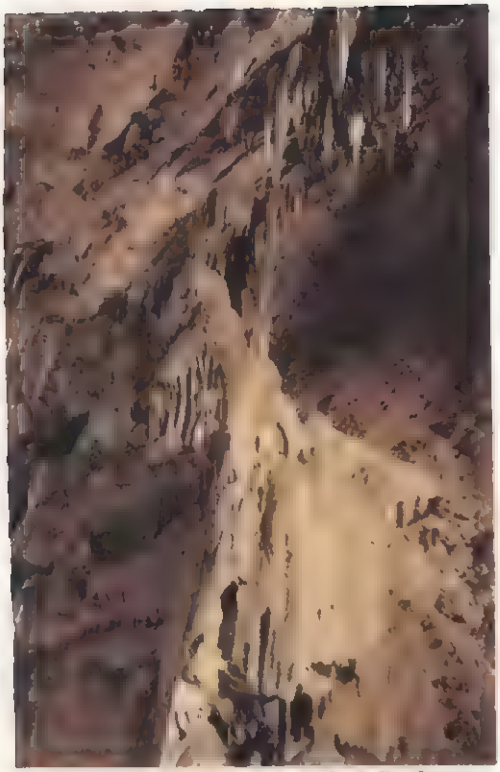


The action of water on limestone can create some very striking effects, such as the Whale's Mouth in Carlsbad Caverns, New Mexico.

In places where rainfall is heavy, a great deal of limestone is removed. For example, the amount of water that falls as rain upon one hectare of land in the Mammoth Cave region in the course of a single year is capable of dissolving one and one-half cubic meters or more of lime

Limestone occurs in more or less horizontal layers in the Mammoth Cave region of Kentucky and in other areas of this state and the neighboring states. This is because the old sea bottom has been elevated bodily to its present position, more than 100 meters higher than formerly. In other places, such as Dalmatia in Yugoslavia and the Carlsbad Caverns region in New Mexico, the limestone has been bent and warped into folds by mountain-making activity. Such limestone beds are tilted at various angles and often broken by fault

Let us see what happens both above and below ground when caves are formed



Richard W. Brooks Photo Researchers

Stalactites and stalagmites are prominent features of limestone caves. Stalactites seem to drip from the ceiling, while stalagmites grow from the floor. Where the two meet, a column may be formed

Joffre

in a region where the limestone beds are horizontal, as in the Mammoth Cave area. Figure 1 on page 98 shows part of the plateau region near Mammoth Cave. The country is almost flat. The very few rivers flow in shallow valleys. The surface of the country is formed by a thin bed of sandstone. Where this thin sandstone bed is worn away, there is a reddish or yellowish soil, which is the residue left behind after limestone has been dissolved. It represents various impurities originally deposited with the limestone when it was laid down upon the sea bottom. Beneath the surface cover there is a massive formation of fairly pure limestone. It is represented in the drawing by a brick pattern -- the standard symbol for limestone.

On the surface of the ground there are several more or less circular shallow pits, called *sinkholes*, formed by the erosive work of water in areas where there are cracks or joints in the rocks. Surface water makes its way from these sinkholes into the ground and eventually into the cracks and *bedding planes* of the limestone. A bedding plane is the surface that separates one bed, or layer, of a stratified rock from the bed below or above it.

The underground water rapidly dissolves channels along the vertical joints or cracks, as well as along the more soluble bedding planes, and caves are formed. The water eventually escapes in springs along the sides of the underground streams.

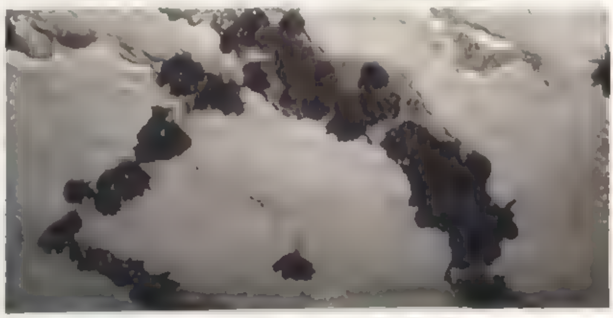
There are literally tens of thousands of sinkholes in an area such as that of the Mammoth Cave. Gradually they become larger as their rims wear back. In time several may join together to form a valley-like depression, or *valley sink*. The country is thus broken up into sinks and valley sinks, as well as real valleys containing surface streams. Beneath the plateau area between the streams, the country is honeycombed with caves. As Figure 2 clearly shows, these have different levels connected with each other by narrow horizontal passageways. Here the underground water has dissolved out tortuous channels along joint planes.

At the lowest level of a cave there may be, as at Mammoth Cave, an underground river, which eventually emerges from the ground as a mighty spring and joins one of the surface rivers of the region. Beneath the level of this surface stream, the cracks and passageways in the limestone are completely filled with water. Not much happens at this depth because the water hardly moves. Above this level, however, rain water seeping down from above constantly enlarges the caverns. In certain places it evaporates and leaves the cave deposits whose fantastic forms delight the visitor's eye.

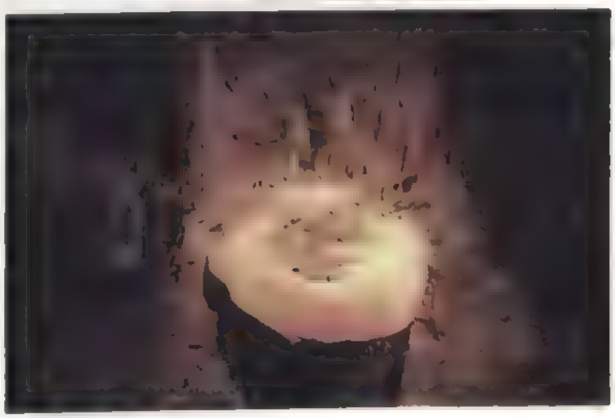
In low-lying regions, such as Florida, Yucatan, and Barbados in the West Indies, the ground water occurs close to the surface. Many of the sinkholes reach down to this level. Springs, ponds, or lakes are formed here, depending upon the dimen-

Bats often inhabit caves. Here a group of bats hangs from the ceiling of a cave while hibernating

C. E. Mohr, Audubon PR



Richard W. Brooks, Photo Researchers



The interaction of water and limestone often produces some unusual effects. This "Palatte" is a formation found in Mitchell Caves in the Mohave Desert, California

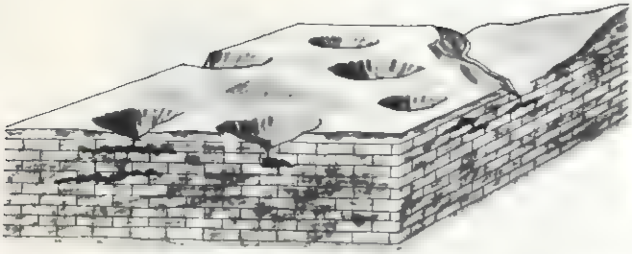


Fig. 1. A representative section of the plateau region not far from Mammoth Cave. The almost flat country is traversed by only a few rivers, flowing in shallow valleys. There is a massive limestone formation (indicated in the drawing by the brick pattern) under the surface cover. The shallow pits are sinkholes. These pits were formed by the action of water.

Fig. 2. In the same region [illegible]uous erosion by water has resulted in the fo[illegible]n of caves. Sinkholes have become larger an[illegible]e have combined to form valley sinks. Underg[illegible]d water, seeping from the sinkholes into the [illegible]stone formation, has dissolved a great deal of lin[illegible]stone. Caves have developed. The caves shown [illegible]e connected by horizontal passageways

In the United States, there are several limestone formations with numerous caves. Here is a map which shows the Flint Ridge and Mammoth Cave system in Kentucky. The low-lying area around the system is riddled with sinkholes, and there is an underground river.

sions of the sinkholes. A[illegible]ve the level of the ground water there [illegible] innumerable small caves and passagewa[illegible]

Not all limestone cav[illegible]are so simple. For example, the famous Carlsbad Caverns have developed in a dipping formation of massive limestone 300 meters thick, underlaid by gypsum (hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$), another soluble kind of rock. In some places this dipping limestone layer has been hollowed out into vast rooms. The largest is 1,200 meters long, 190 meters wide, and 100 meters high.

In the Karst region of Dalmatia, Yugoslavia, the limestone beds are folded. Caves, therefore, have a great variety of shapes. The surface of the country is pitted with numerous sinks, which in many cases have steep-walled sides. These are often fluted, or grooved out, by the water washing over them as a result of the heavy rainfall of the region. The larger sinks or valley sinks are often flat-floored. Rivers emerging from their sides wander over these flat surfaces to disappear again in a cave at the other end of the valley. In certain places elongated sinkholes or chains of sinkholes mark the course of an underground stream. The name *karst topography* is used to describe landscapes that show the same features as the Karst region.

If the sinks and valley sinks are enlarged still more, only small remnants of the intervening plateau area will be left. In time the country will show scattered, isolated

hills, each hill honeycombed with caves. Such hills are called *haystack* or *pepino* hills in Puerto Rico. Similar formations occur in the Cockpit Country of Jamaica and in Cuba, west of Havana. The Cuban hills have steep, fluted walls, rather suggesting a series of organ pipes. They are called the Sierra de los Organos, or Organ Mountains.

Limestone caves may be either dry or wet, depending upon the rainfall of the region outside. There is a certain time lag, amounting to days or even weeks, between a rainfall outside the cave and the appearance of water inside of it.

The floors of many limestone caves are deeply covered with a reddish or yellowish clay, washed into the caves from above. It represents the clayey particles left behind when limestone containing clay is dissolved at or near the surface. Some cave passageways are completely filled with such clay deposits. They must be excavated before visitors can enter.

It is doubtful if limestone caves ever collapse, though some people think that natural bridges are formed in that way. There is not a single natural bridge in the Mammoth Cave region, and few natural bridges in other limestone areas. It is likely that the walls and roofs of caves, instead of collapsing, gradually dissolve away in the course of time so that, ultimately, only small remnants of the original roof remain. Occasionally, blocks of rock are loosened and drop off the ceiling, but such rockfalls are insignificant when we consider the total volume of the caves. Natural bridges are formed more frequently in sandstone and other rocks than they are in limestone regions. They result partly from the erosive action of water, especially the sidewise cutting of streams, and partly from weathering, including wind action.

No two limestone caves are alike. Some of them are entered from the side of a hill, others through the roof by way of a sinkhole. The passageways of many caves are low. Others are high enough to allow a tall person to walk erect. Some caves are not particularly noteworthy. Others offer astonishing views. In Mammoth Cave, for instance, one comes suddenly at the end of a passageway to a barricade. From this one can look down into a tremendous pit. Above it is a vast dome towering up almost to the surface of the plateau far above. The walls, carved into fluted columns, reveal tier upon tier the horizontal limestone beds of which the entire region is built.

CAVE DEPOSITS

Most visitors to limestone caves are particularly interested in the variously shaped and statuelike deposits laid down in the course of the ages. These deposits are called *speleothems*, from two Greek words meaning "set down in caves." They assume an amazing variety of forms. There are long, thin straws and gleaming icicles suspended from the roof, stubby posts rising from the floor, flowing curtains and draperies, terraced minarets and towers, frozen cataracts, and a host of other wonders.

To explain formation of these deposits, let us recall that rain water, percolating downward through the rocks and charged with carbon dioxide, reacts upon limestone and forms calcium bicarbonate. This substance is then carried off in solution. The calcium bicarbonate-laden water finally makes its way downward to the ceiling of a cave. Often it evaporates: carbon dioxide gas is liberated and calcium carbonate, generally in the form of calcite, is deposited. The chemical reaction involved is as follows:

$$\underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2} \quad \underset{\text{yields}}{\longrightarrow}$$

$$\underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}$$

The calcium carbonate deposit takes the form of a little circle of stone. Other drops leave their deposits here, too, and in time a hollow stone tube begins to grow downward from the roof. A tube of this type is called, appropriately enough, a *soda straw*. It may reach a length of a meter or so. Frequently water passes down the outside of the hollow tube as well as through its center. In time there will be a calcite formation in the form of an icicle. The

stony icicles may form a straight row under a joint in the cave roof. They may be several meters in length.

STALACTITES AND STALAGMITES

All calcium carbonate formations suspended from the roofs of caves are called *stalactites* from the Greek *stalaktos*, meaning "oozing in drops." Some stalactites develop twisting branches, which sometimes grow upward—nobody knows why. These branching formations are called *helictites*, from the Greek *helix*, meaning "spiral." Where there is a more or less even flow of water along a narrow crack in the roof, the stony deposit may take the form of a curtain or drape. In some cases the suspended sheets have brown streaks caused by the presence of limonite, or iron rust.

Instead of evaporating on the cave roof, a drop of water may fall to the floor right below a stalactite icicle. As it hits the floor, the drop splashes and leaves its calcium carbonate deposit over a comparatively wide area. Other drops land on the spot. In time a blunt and rounded deposit is built up. This is called a *stalagmite*, from the Greek *stalagmos*, meaning "a dropping." Both stalactite and stalagmite formations are called *dripstone*.

In the course of the ages a stalactite may unite with the stalagmite that has developed underneath it, and they may form a *column*. Since stalactites often develop in a row coinciding with a crack in the roof of a cave, there will be a corresponding row of columns. In time, these may become a *palisade* and finally a wall, partitioning the cave off into rooms.

Water containing calcium bicarbonate in solution may make its way down projecting ledges in caves and gradually evaporate, leaving a formation aptly called a *frozen waterfall* or a frozen Niagara. Deposits of this kind are called *flowstone*. In some cases, pools on the floor of a cave may overflow and build up rims of calcite. The resulting formation is known as *rimstone*.

A bit of foreign matter in a pool may serve as a nucleus for successive layers of calcite. Eventually a round cave pearl will be built up. In comparatively rare cases a calcite film may form around a bubble in the pool, forming a calcite bubble that floats on water—an exquisite trinket so fragile that it will crumble away at the slightest touch.

Calcium carbonate deposits in caves generally consist of calcite. Sometimes, however, the calcium carbonate forms crystals of aragonite as it passes from solution. These crystals may be combined in a beautiful flowerlike cluster, known as an *anthodite*, from the Grrek word *anthos*, meaning "flower."

Sometimes gypsum may be carried into the cave as water seeps in, and may leave deposits on the cave surfaces as the water evaporates. The gypsum deposits may take the form of elaborate rosettes, several centimeters in diameter and often of exquisite beauty. Epsomite, or magnesium sulfate ($MgSO_4 \cdot 7H_2O$), may also occur in caves in the form of masses of fine fibrous crystals coating the walls.

OTHER KINDS OF CAVES

Caves have developed through the dissolving action of water in other rock formations—in dolomite and marble, which are closely related to limestone, and also in gypsum. Such caves are insignificant in number compared to limestone caves and we need not discuss them here.

A considerable number of caves are formed by overhanging ledges. In Figure 3 we show the cross section of two such caves. The upper cave is quite small—just large enough to provide a person with protection from the rain. It has resulted from the disintegration of some weak formation, such as shale or limestone, or even of poorly consolidated sandstone, capped by a more resistant bed, such as hardened sandstone. This bed is strong enough to project outward even when deprived of support underneath.

The lower cave shown in the diagram extends somewhat further into the hillside but soon comes to an end. Such a cave may develop from wind action, which sweeps away small particles of earth as soon as they become detached from the sides of the cave. It may result from the seepage of water or from the burrowing of animals, or

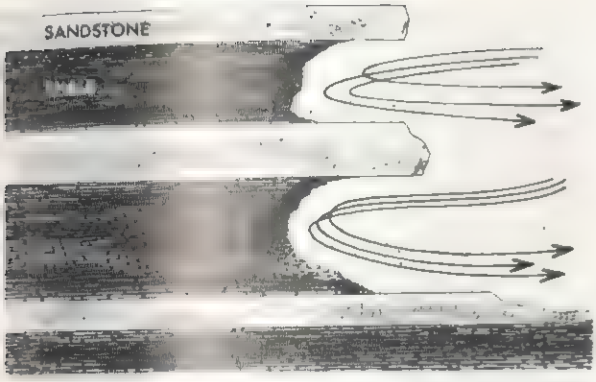


Fig. 3. Two caves formed by the disintegration of shale, a weak rock formation, sandwiched between layers of sandstone, a harder formation. The caves may have been "dug" by the action of wind or water or the burrowing of animals.

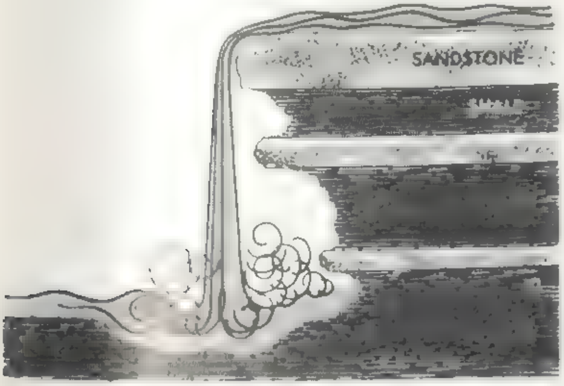


Fig. 4. The swirling action of a spray beneath a waterfall can hollow out caves, as the diagram indicates. The relatively soft shale has been hollowed out more than the harder sandstone. An example of this type of cave is the Cave of the Winds at Niagara Falls, New York.

the work of people.

A certain number of caves, such as the one shown in Figure 4, have been formed by the swirling action of spray beneath a waterfall. The Cave of the Winds at Niagara Falls is an example. Visitors descend into it by elevator and can stand behind the roaring sheet of water. From time to time tremendous blocks of rock break off from the ledge above, causing slight tremors.

A certain number of caves result from the action of ocean waves. They occur along coasts where the rocks are weak, cracked, or conspicuously jointed and, therefore, readily affected by the pounding of the waves. Sea caves formed in this way usually do not extend very far into the land. The Blue Grotto at Capri, a famous islet in the Bay of Naples, Italy, is the most famous of all sea caves and one of the largest. It is 50 meters long, 30 meters wide, and 15 meters high. The roof of the entrance is only about one meter above water. Sunshine fills the grotto with a dazzling blue light. Many other caves occur along the coastal area in this region. They are all limestone formations eroded by the action of the waves and not dissolved away, as in the case of most limestone caverns.

Fingal's Cave on the uninhabited island of Staffa, off the Scottish coast, is another well-known sea cave. Cut into a basaltic formation, its walls and entrance way appear to be supported by columns of basalt. The cave is at sea level and is entered by a wide arched opening 20 meters high and 70 meters wide. It has been developed along a series of joint planes. It reaches inland about 15 meters and then ends abruptly.

Another type of cave is formed under a lava flow. It results when the outer crust of the lava hardens while the interior is still molten. When this molten material flows away, the roof remains, and a long cave, or tunnel, is formed. From the ceiling of such a cave hang solidified drippings of lava. Such caves are common in the Hawaiian Islands.

Caves sometimes develop in banks of sand and clay. The turf above forms a roof over cavities in the loose soil beneath. Cliff swallows often build their nests under the overhanging ledges of sod. Caves of this kind are often quite large and are apt to collapse suddenly.

CAVE EXPLORERS

The eternal allure of caves, of whatever type they may be, attracts a considerable number of daring explorers—men, women, even children—who call themselves *spelunkers*, from the Latin *spelunca*,

for cave. A true spelunker scorns the carefully laid out routes of commercial caves that cater to visitors. He explores little-known passageways of familiar caves, as well as caves that are not well-known and are relatively unmapped.

Sometimes spelunkers become more or less serious students of caves, and they graduate into the ranks of *speleologists*, or cave scientists. There are geologists and other professional scientists, as well as enthusiastic amateurs, in the ranks of speleologists. They have many different interests. Some are primarily concerned with the surface above and in the vicinity of a cave. Others map the cave itself. Still others study its geological formations, or its life, or its underground streams.

LIFE IN CAVES

There are three different zones in caves: the area just inside the entrance; a twilight area, in which at least a certain amount of light penetrates; and the portion of the cave that is in total darkness. Each of these areas offers a particular type of environment for living things.

Considerable numbers of plants and animals are found in the two outer zones. Among the plant forms are algae, lichens, mosses, and ferns. The animals include bears, weasels, raccoons, rodents, bats, and birds. Some of them may live quite far within the cave, even in the zone of complete darkness. A considerable number of the animals that live in the twilight zone are born and raised there and many of them die there. The remains of extinct animals, as well as of living forms, have often been found in this area.

Perhaps the best-known residents of caves are the small flying mammals called bats. A number of different species are found in caves, hanging head downward from cave roofs or the higher parts of walls. Some use caves for hibernation. Others dwell there, leaving at regular intervals in search of food.

In many caves the excrement of bats forms deep deposits on the cave floors. This excrement, which is called *guano*, is an important source of commercial fertilizer. The bat guano in Mammoth Cave was employed during the Civil War to make saltpeter, a nitrate used in the manufacture of explosives. The old wooden tanks and pipes that served in the manufacturing process are still shown to visitors.

Among rodent cave-dwellers is the cave rat, *Neotoma magister*, which builds its nest of shredded bark and similar substances, far within the cave—sometimes in the area of total darkness. *Neotoma magister* leaves the cave to seek the nuts and seeds on which it feeds.

Of the birds that nest in caves, the most remarkable, perhaps, are the guacharos, or oilbirds, of Venezuela and Trinidad. These birds, with a wingspread of more than a meter, live in the dark areas far within caves. They fly out at twilight to seek food and return before daylight. Sometimes several thousand guacharos dwell in a single cave. They make a terrific noise as they emerge. Other bird inhabitants of caves include owls, phoebes, and jackdaws.

A good deal of food material is brought

The oilbird, or guacharo, nests in the caves of Trinidad. Because the caves are so dark, the birds must rely on sonar to find their way.

Russ Kinne, Photo Researchers

into the zone of utter darkness from the outside. Streams wash in organic materials derived from plants. Fungus spores are blown in as wind circulates in the cave. Seeds brought in by animals may sprout. After a few days of sickly growth the seedlings die and add to the store of organic food. All of these materials form the basis of a food cycle involving a varied population of animal forms and a few plant forms, which spend their entire lives underground.

Generally speaking, only plants that can thrive in the absence of sunlight (plants such as fungi and bacteria) are to be found deep within caves. Mushrooms thrive under such conditions. In fact, they are cultivated in caves in many areas. A species of mold of the genus *Penicillium* also flourishes in caves. This mold is used to ripen Roquefort cheese in caves in southern France. Plants requiring sunlight sometimes germinate in the totally dark area of caves, but they cannot reach maturity and cannot reproduce.

Among the animals that live out their lives in the zone of total darkness in caves are worms, fishes, amphibians, insects, spiders, and crustaceans. Generally speaking, they are either predators, eating other animals, or scavengers, living on decaying organic matter.

An interesting aquatic animal found deep within caves is the blindfish *(Amblyopsis spelaeus)*, found in Kentucky caverns. *Amblyopsis* has become completely etiolated, or bleached, and its eyes have been reduced to mere functionless vestiges. To compensate for lack of vision, *Amblyopsis* is provided with highly sensitive papillae, or protuberances, arranged in ridges on the front and sides of the head. Blind crayfish are also found in caves.

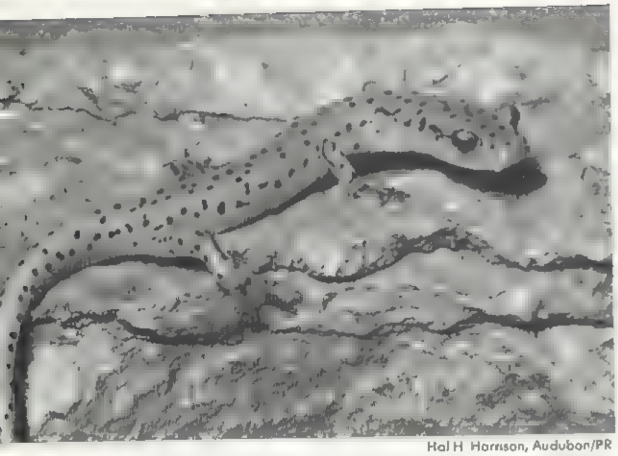
Amphibian inhabitants of caves include several species of salamanders and frogs. Certain cave salamanders have degenerate eyes, almost or entirely covered by fused lids. Others, found in various Austrian caves, have no eyes at all. Some cave salamanders are white; others are spotted.

Arthropods, including insects, spiders, crustaceans, and their kin, are the principal nonaquatic inhabitants in the totally dark areas of caves. They include centipedes, spiders, mites, moths, beetles, flies, crickets, and fleas. Among the most interesting of the insect inhabitants of caves is the fly called *Bolitophila luminosa*. Its larvae, known as glowworms, live in dense colonies, hanging from cavern roofs, in the caverns at Waitomo, New Zealand. They spin silken threads that hang down and entrap small insects that have found their way into the caverns. In the darkness, the cavern roof is lighted up by the glowworms like a splendid midnight sky. Certain mollusks, including snails and slugs, occur in caves, feeding on decaying plant materials and serving as food for salamanders and frogs.

CAVES AND MAN

There is plentiful evidence that prehistoric man dwelt in large caverns in various regions of Europe and Asia. Many generations of people must have lived in caves, for we find their tools, artifacts, and household refuse piled up layer upon layer, together

Sight is useless to many animals that live in caves This blind cave fish, a resident of underground streams, shows only a trace of eye sockets



Hal H. Harrison, Audubon/PR

Some amphibians also inhabit caves, some even the deepest recesses. Here, a spotted cave salamander. Other species of cave salamanders are typically white.

with the bones of the animals that they hunted. The walls of some of the caves where prehistoric man dwelt contain fine specimens of art. The cave paintings at Altamira, Spain, and Font-de-Gaume, France, are particularly notable.

The ancient Greeks wrote of certain primitive peoples whom they called *troglodytes*, or cave dwellers. They lived in caverns in many places around the shores of the Mediterranean, especially in Libya and eastward to Egypt. In some cases ancient peoples built underground cities, cut out of solid rock. Among these were Edrei, in Syria, and Petra, in Jordan. The ancient Chinese also used caves as dwelling places.

Today, too, people live in cave dwellings. In certain parts of China and Austria the inhabitants excavate rooms in loess deposits. People also dwell in caves in various parts of France, Spain, and Italy.

Caves have served as places of refuge for perhaps millions of years. When the Romans attacked Gaul, the inhabitants often sought refuge in caves. Centuries later, these caves served as shelters during the Saracen invasion. Medieval annals abound in accounts of cave refuges. In the United States, it is said that Mammoth Cave was used as a "station" in the Underground Railroad, which helped slaves to escape from the South before the Civil War.

Jim Hubbard, Photo Researchers

Cave dwellers are known as *troglodytes*. This photo shows a group of gypsy troglodytes near their cave homes in Spain.

Caves have also been widely used as places of religious worship. In Egypt, temples were sometimes carved out of solid rock and provided with ornate entrances. There are wonderful cave temples, going back to ancient days, in India, particularly on Elephanta, an island in Bombay harbor. Many Buddhist temples were established in Chinese caves. In western Europe several famous monasteries were originally cave hermitages, later enlarged.

Various other uses have been found for caves. They have been used as spacious prisons. Brewers in St. Louis, Missouri, once stored their beer in caves. At least one natural cave serves as a railroad tunnel—the Natural Tunnel, used by the Southern Railroad in southwestern Virginia. Occasionally subterranean streams in caves have provided communities with water. This source of supply has to be used with caution, however, since sinkholes serve as garbage pits in certain areas.


Victor Hessler, University of Alaska

The aurora borealis. A display such as this is probably due to solar radiation hitting atmospheric gases and causing them to glow.

ATMOSPHERE

by Harlan T. Stetson

We are born, live our lives, and die at the bottom of an ocean of air that we call the atmosphere. It surrounds the solid and liquid parts of the earth—the land and water—but it is just as truly a part of the earth as they are.

A MIXTURE OF GASES

The atmosphere is a mixture of gases. Nitrogen makes up almost four fifths of it and oxygen a little more than one fifth. There are also small quantities of other gases, including argon, neon, helium, krypton, xenon, carbon dioxide, hydrogen, and ozone, which is a form of oxygen. We likewise find in the atmosphere a considerable amount of water vapor that has evaporated from oceans, lakes, and rivers. The solid earth holds all these gases to it by the pull of its gravitational attraction.

The oxygen in the atmosphere makes fire possible, for ordinary burning is the combination of oxygen with the carbon of coal, or oil, or wood, or other fuel. Breathing is also part of a burning process. We take oxygen into our lungs and the blood carries it to all parts of the body. The oxygen combines with carbon in the body cells to produce heat and energy and a waste gas, carbon dioxide. The blood then carries the carbon dioxide to the lungs, which breathe it out.

Nitrogen also plays its part in burning. Because it is chemically inactive, it slows down the process of oxidation, or combining with oxygen. We could not breathe pure oxygen for any length of time. If burning took place in pure oxygen, fires would be intensely hot.

Another very important part of the atmosphere is carbon dioxide. Plants absorb this gas and utilize it in the manufacture of food in the green leaf by the process known as *photosynthesis*. Oxygen is given

off in this process. Animals inhale oxygen and give off carbon dioxide as a waste product of breathing. The proportion of carbon dioxide to oxygen in the air may vary. Thunderstorms seem to increase the concentration of carbon dioxide locally. The total volume of atmospheric carbon dioxide has been increasing steadily for the past few centuries, perhaps because of the increased burning of fuel by expanding industries.

About 25 kilometers above the earth there is a layer of ozone. Ozone is a kind of supercharged oxygen. Each ozone molecule contains three atoms of oxygen, while there are only two atoms in the ordinary oxygen molecule. The ozone layer of the atmosphere absorbs a great deal of the ultraviolet light of the sun.

WHAT THE ATMOSPHERE DOES

The atmosphere moderates the extremes of heat and cold upon the earth. The air acts much like the glass roof of a greenhouse. It reduces the change in temperature between day and night, summer and winter. The heat rays of the sun penetrate the air and warm the earth's surface during the day. The overlying atmosphere traps this heat so that it escapes more slowly into space, moderating the cold of night. Were it not for our atmosphere, the earth's surface would suffer extremes in temperature.

The atmosphere protects man from a steady hail of meteoritic particles. It is estimated that over one hundred thousand million meteors strike the earth's atmosphere every twenty-four hours, but as they come in contact with the air most of them are reduced to gas and dust through friction. It is probable that the atmosphere also protects man from certain types of electrically charged particles from the sun.

Because of the changes that take place within the atmosphere, and only because of these changes, we on the earth experience various types of weather. Without the atmosphere there would be no rain to fall upon parched ground and make plants grow. There would be no wind and no clouds.

If there were no atmosphere, the sky above the earth would appear dead black. The beautiful blue of a clear daytime sky, the colors of sunrise and sunset, and even rainbows could not exist were it not for the presence of an atmosphere. The tiny molecules of gases and the dust particles in the air break up and scatter the light of the sun into the various colors of which it is composed.

The blue part of sunlight is usually scattered more than the other colors comprising sunlight. Therefore, the sky appears blue. In the morning and evening, when the sun's rays come more slantingly through the layers of the atmosphere, other colors—red, orange, yellow, green—are scattered at the horizon. When there is an unusual amount of moisture in the air and the sun is shining brightly, the particles of moisture sometimes break up the sunlight into all its colors to form the colored band of the rainbow.

ATMOSPHERIC PRESSURE

We do not ordinarily think of air as having very much weight. Indeed, we are likely to think of space that is not occupied by solid objects as "empty." But suppose we carefully weigh a bottle filled with air and then pump out as much of the air as possible with an air pump. When we weigh the bottle again, we find that it is not so heavy as before. The loss in weight corresponds to the weight of the air that originally filled the bottle. Physicists have calculated that a cubic meter of air weighs about 1,300 grams—quite an appreciable amount. The total weight of the atmosphere is something like 5,200,000,000,000,000 metric tons. This means that the weight of air at the earth's surface brings about a pressure of one kilogram per square centimeter.

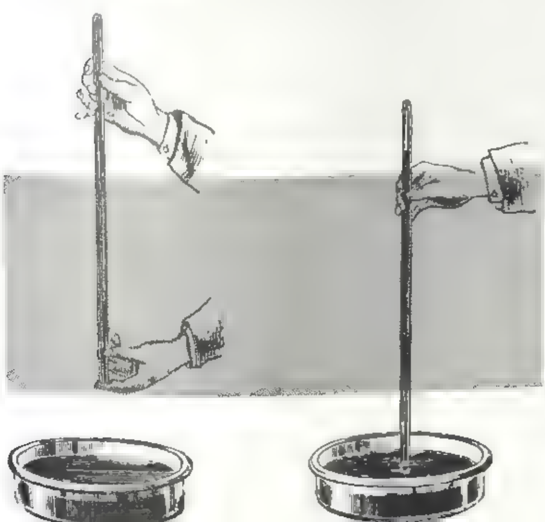
The first knowledge of the fact that air has weight and that it exerts pressure goes back to the early part of the seventeenth century. The Italian scientist Galileo Galilei was puzzled when he observed that water could not be drawn up a pipe or tube by a pump to a height greater than 10⅓ meters. His friend Evangelista Torricelli also became interested in the problem. He argued that atmospheric pressure caused

the water to rise in the pipe. When a pump is worked, some of the water in the pipe is removed. The atmosphere is continually pressing upon the water source to which the pipe is connected. Pressure causes water to rise in the pipe and thus replace the water that has just been removed. Water can rise in the pipe to a height of only 10⅓ meters at most, because the pressure of the atmosphere would not be great enough to raise it above that height.

Torricelli knew that mercury is more than thirteen times as heavy as water. Hence he reasoned that the pressure of the atmosphere could raise a column of mercury to less than one-thirteenth the height of a column of water. He tried this out with a long glass tube closed at one end and filled with mercury. He turned the tube upside down, with the open end immersed in a dish partly filled with mercury. With no air in the tube above the mercury, the mercury column fell to a height of very nearly 76 centimeters, or less than one-thirteenth the height of the water column that could be sustained by means of atmospheric pressure.

Atmospheric pressure decreases with increasing altitude. This is because there are fewer molecules of air at higher altitudes, and these collectively exert less pressure. The pressure also varies under different weather conditions. To measure such changes in pressure, we use the instrument called the *barometer*. There are several kinds of barometers. The mercury barometer is based on the Torricellian apparatus that we have already described. In the aneroid barometer the action of atmospheric pressure in bending a metallic surface is made to move a pointer.

Torricelli's barometer. He sealed one end of a glass tube and filled the tube with mercury. Stopping up the open end with his finger, he dipped the tube under the surface of the mercury in the bowl.



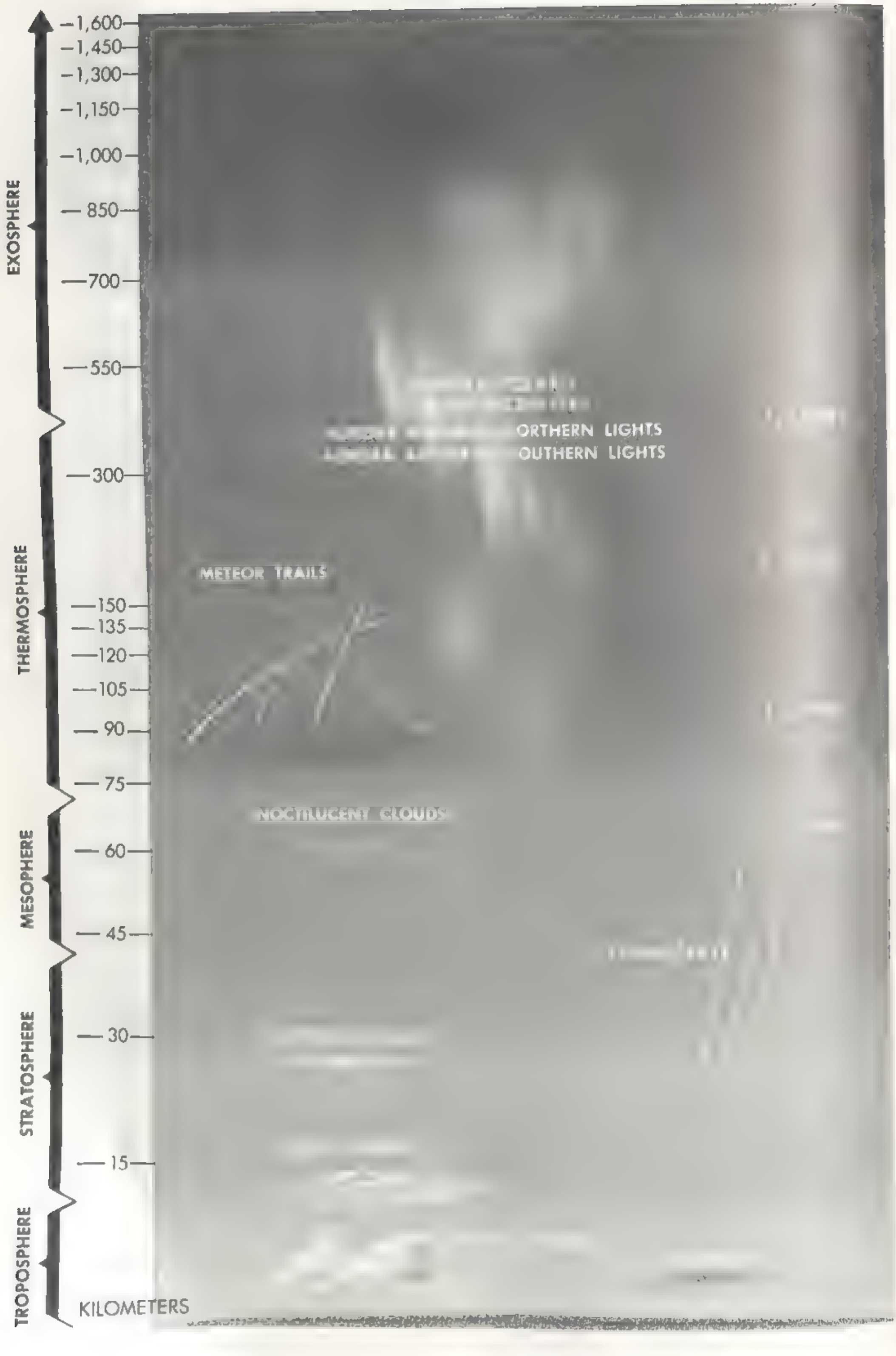
EFFECTS OF AIR PRESSURE

Man, like every other creature living on the face of the earth, is greatly affected by atmospheric pressure. You will realize how staggering the total amount of pressure on a human body is if you recall that about one kilogram-force of air presses upon each square centimeter of its surface. But because there is air within our bodies as well as outside, we feel no discomfort under ordinary conditions.

When, however, we are suddenly transported to great heights by airplanes, we do feel uncomfortable. The higher we go, the less pressure the air outside exerts upon our bodies, and the balance between the inner and the outer pressure is disturbed. For this reason pilots of commercial airlines rise slowly to give ample time for their passengers to adjust to the reduced pressure without discomfort. Some airplanes that are to travel at very great heights are so built that the pressure within their cabins can be maintained as the planes reach higher altitudes. When a plane equipped with such a pressurized cabin is at a height of 6,000 meters, the pressure inside the cabin is about what it would be in the outside air at an altitude of 2,400 meters. In planes that do not have pressurized cabins, added oxygen must be supplied through the use of masks or similar devices when the planes rise above 3,000 meters or thereabouts.

STUDYING THE ATMOSPHERE

How deep is the vast ocean of air that surrounds us? It is difficult to say, for the atmosphere grows rapidly thinner as we rise above the earth. We do know that balloons, which must be buoyed up by the outside air, have risen to considerable distances above the surface of the earth.


EXOSPHERE
THERMOSPHERE
MESOPHERE
STRATOSPHERE
TROPOSPHERE
KILOMETERS
1,600
1,450
1,300
1,150
1,000
850
700
550
300
150
135
120
105
90
75
60
45
30
15
METEOR TRAILS
NOCTILUCENT CLOUDS

Weather experts often send inexpensive small balloons into the upper air. These balloons carry instruments for measuring temperature, moisture, and so on. They are also provided with miniature radio sending stations. The radio apparatus is battery operated and is very light and compact. As it rises it automatically sends back by code the atmospheric pressure, the temperature, and the humidity at frequent intervals. These sounding balloons, which are called *radiosondes*, have ascended to a distance of 60 kilometers or more.

A worldwide project is being considered to send several thousand balloons aloft for long periods at heights from less than two kilometers to about 25 kilometers, to keep track of atmospheric conditions. A number have been launched since 1966, from New Zealand. These superpressure balloons are designed to fly at constant altitudes. When equipped with temperature and humidity sensors and interrogated and located from a satellite, they provide very important new data.

Air exploration is aided by advances in both rocketry and instrumentation. Some rockets have been used to release chemicals into the upper atmosphere by scientists wishing to study the reactions of the gases there. To discover the density of air at different heights, rockets release instrument-carrying metal spheres at given altitudes. The spheres' varying rates of fall indirectly determine the densities of the air layers they pass through. Globe-circling artificial satellites have taken photographs of cloud formations from above. These same satellites hold great promise as platforms for remote probing and sounding of atmospheric conditions.

Less glamorous but equally important methods and devices are also used to examine the atmosphere. Among these are the conventional airplane and ship. Ground instruments, such as radio and radar, send out electrical signals that tell us much about conditions many kilometers up. Astronomical observations reveal a great deal, not only about our own atmosphere, but also about the atmospheres of other planets. By the sizes and positions of meteor trails, sometimes almost 300 kilometers high, scientists have learned a great deal about the extent and state of the upper atmosphere. They also know that twilight is caused by tiny dust particles scattering the light of the setting sun more than 40 kilometers above the earth. Cosmic rays from outer space penetrate our atmosphere and react with it, causing showers of secondary radiation that are highly characteristic.

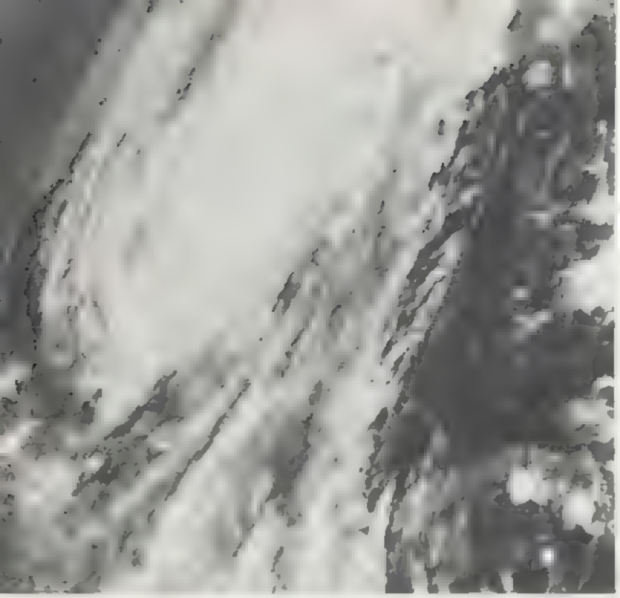
The distribution and amount of dust falls are controlled by the air currents and winds in the upper atmosphere. For example, enormous volumes of meteoritic dust enter the atmosphere daily from space. Radioactive particles, blown perhaps thousands of meters upward in past atomic explosions, are also moved about by the winds. These meteoritic and radioactive dusts settle slowly over the earth, forming distinct geographic patterns as they are dispersed by the different systems of air streams.

ATMOSPHERIC STRUCTURE

By the various means described above, meteorologists and space scientists have built up a fairly detailed picture of the earth's atmosphere, from the surface of the ground to hundreds of kilometers up. They have found the atmosphere to consist of five more or less distinct layers. The altitude limits of these layers are not rigidly defined, because the actual heights vary in the atmosphere, depending on geography and season. Roughly speaking, however, the distances of these layers above the earth are approximately as follows:

(1) The troposphere, 0–10 kilometers;
(2) The stratosphere, 10–40 kilometers;
(3) The mesosphere, 40–70 kilometers;
(4) The thermosphere, 70–400 kilometers;
(5) The exosphere, 400 kilometers and beyond.

The troposphere (0–10 kilometers up). The troposphere is the air with which all human beings usually have intimate contact, since it is the very stuff we breathe and is also the seat of weather and climate.



NOAA

Advanced methods for studying the atmosphere include satellite technology. This satellite photograph shows atmospheric pattern characteristic of a hurricane.

The troposphere is the densest part of the atmosphere. Air pressure drops with increasing altitude, as we have already pointed out. There is more water vapor and carbon dioxide in the troposphere than in any other layer. This fact is highly important, for the two gases in question affect the heat balance of the earth, particularly with respect to infrared radiation. Water vapor absorbs some infrared. Carbon dioxide and water vapor trap much of the infrared that is being reradiated from the sun-heated ground.

The troposphere, therefore, is heated by the ground as well as by the sun. In fact, its temperature, around 25° Celsius on the ground, generally drops about 5° for every kilometer of altitiude gained, until it reaches a low of around −60° Celsius at a height of about ten or eleven kilometers. The average air temperature also drops northward and southward from the equator.

Much of the solar radiation reaching the earth is absorbed by the ground, air, clouds, water, and ice. The rest is reflected back into space. A great proportion of the short-wave radiation—ultraviolet, X rays, and cosmic rays—from the sun and outer space is absorbed or scattered in the upper atmosphere before it reaches the troposphere or the ground.

The layer of air up to a few meters above the ground is a great importance to many living things, including man. The branch of atmospheric science that deals with the characteristics of this lowermost tropospheric layer is called *micrometeorology*, or "small-scale meteorology."

The stratosphere (10 to 40 kilometers up). The stratosphere is less dense than the underlying troposphere. It contains much the same gases, except that there is less water vapor. At an altitude of about 25 kilometers, much ozone is concentrated. It absorbs most of the ultraviolet radiation of the sun and thus is heated. From a low of −60° Celsius at ten kilometers the stratospheric temperature rises slowly up to the base of the overlying mesosphere at about 40 kilometers. The temperature of the stratosphere increases in the summer as the distance from the poles decreases. The reverse is true in the troposphere.

Although clouds are rare in the stratosphere, there is increasing evidence that this layer of the atmosphere has a system of winds and slow cycles of change all its own. Among the important features of the lower stratosphere and the upper troposphere are the *jet streams*, fast world-circling air currents that are surrounded by slower ones. Although their speeds, directions, and locations may vary with the seasons, the jet streams are generally quite persistent. Circulation patterns are generally the same in both hemispheres. In the Northern Hemisphere during winter, there is a jet stream at about 10 kilometers altitude over the southern United States, blowing from the west at more than 130 kilometers an hour. Above the Arctic regions, there is a vast winter whirlwind in the stratosphere, also flowing from west to east. The polar jet stream is part of this, at a height of 30 kilometers or more. In the spring, when sudden, or explosive, warming of the Arctic stratosphere takes place, circumpolar circulation reverses direction, now blowing from east to west. The temperate-zone jet streams shift some distance polewards during the summer, maintaining a west-to-east direction but losing much of their winter velocities in the process.

The above-described seasonal change in the system of stratospheric circulation is associated with important changes in the troposphere. In the first place, the jet streams are located most frequently over the stormier parts of the troposphere. The explosive spring warming and jet reversal over the Arctic and the Antarctic permit immense volumes of warmer stratospheric air to invade the troposphere in those places. Stratospheric summer temperatures over the Arctic are actually higher than those at certain corresponding altitudes above the equator. Changes in the stratosphere's circulation may be due to atmospheric phenomena hundreds of kilometers above the earth. Solar flares, or outbursts, have been blamed for triggering electrical reactions in the upper part of the air. These reactions may affect the positions of the jet streams. The changes in the latter may then in turn influence weather in the troposphere.

Not only do the jet streams bring warmth to the poles in spring, but in the winter they prevent warm air from entering the Arctic and Antarctic. Explosive warmings of polar stratosphere sometimes occur in the winter, with alterations in jet flows. The stratosphere may affect the polar regions so greatly that, even during the winter, the troposphere there may receive ozone from above. The circulation of the stratosphere is generally much slower than that of the troposphere, and it is more far-reaching from the geographical point of view.

The mesosphere (40 to 70 kilometers up). The composition of the mesosphere is not unlike that of the stratosphere below. The gases are less dense of course. Carbon dioxide and water vapor are of little importance. The mesosphere has a layer of ionized, or electrified air – the so-called *D layer* – extending 50 to 70 or more kilometers above the earth. It is caused by the action of solar ultraviolet on the air molecules and is charged with electrons, or particles of negative electricity. Ozone also occurs in the mesosphere, where it is formed by the action of solar ultraviolet and X rays on oxygen. The temperature, from a low

Westinghouse Electric Corp

Lightning would not occur if there were no atmosphere. Actually, none of our familiar weather events would occur in the absence of an atmosphere. The sky would always appear black.

of −60° Celsius at 10 kilometers (in the stratosphere) rises to 0° Celsius at an altitude of 50 kilometers. Then it drops to around −90°Celsius at about 80 kilometers above the surface of the earth.

Various phenomena occur in the mesosphere. Cosmic rays from outer space shatter numerous atmospheric atoms, and thus form showers of secondary atomic particles that may penetrate the earth. So-called *noctilucent* or "night-shining" *clouds*, perhaps water vapor or meteor dust, lie at 55 to 80 kilometers altitude. *Airglow* – light due to reradiation of sunlight by heated atmospheric particles – takes place at the smae heights. The *auroras* – northern and southern lights – may extend down into the mesosphere.

The thermosphere (70–400 kilometers up). The thermosphere is in many ways radically different from the other atmospheric layers. Ozone, carbon dioxide, and water are virtually absent. The over-all density of the thermosphere is extremely low, less than one-millionth that of the air at ground level. Yet, tenuous as it is, the air in the thermosphere is still dense enough to burn up fast-moving meteors, whose fiery trails have been observed as high up as 300 kilometers. Because of the radiative energy from space, the thermospheric

gases are broken up into atoms, instead of being combined in molecules, as in the lower atmosphere. For example, in the lower atmosphere we find oxygen molecules (O_2), each made up of two atoms. In the upper thermosphere, the gases tend to separate into density layers, because the earth's gravity affects them.

Most of the gas atoms of the thermosphere are electrically charged, or ionized, by radiation from the sun and elsewhere. Furthermore, free particles of negative electricity, or electrons, are abundant, increasing with altitude. There are three distinct ionized regions—the E, F_1 and F_2 layers. The *E layer*, caused mainly by solar X rays, is about 90 to 120 kilometers above the earth. It consists mainly of nitrogen and oxygen. The overlying F layers, at altitudes ranging from about 150 to more than 300 kilometers, are due primarily to solar ultraviolet. Oxygen atoms predominate in the *F_1 layer*, nitrogen ions in the *F_2 layer*.

These thermospheric layers are very important for communications. They reflect radio waves back toward earth, thus permitting worldwide coverage. During solar flares and intense sunspot activity, atmospheric ionization is so increased that radio waves are absorbed rather than reflected, and communications blackouts take place.

There is a wide range of temperature in the thermosphere. From a low of about −90° Celsius at 80 kilometers altitude, the temperature rises to several thousand degrees at 500 kilometers and higher, into the exosphere. A great part of this intense heat, if not all of it, is due to fierce solar energy and other kinds of radiation bombarding the atmosphere at these heights.

The gases of the thermosphere are not inert, but move in regular and irregular fashion. Motions of ionized gas generate electricity, and so the thermosphere has its share of electrical currents and winds. The sun and moon, through their gravitational pulls, cause periodic movements in the atmosphere, much as in the ocean. Solar thermospheric tides are immense, perhaps more than two kilometers deep. They cause tremendous flows of electricity that create daily variations in the earth's magnetic field. Electrical air currents from both the Northern and Southern Hemispheres move toward the earth's magnetic equator, not quite coinciding with the geographic equator. Here they merge to form the so-called *electrojet*, an eastward-flowing current about 100 kilometers above the earth.

The auroras, sometimes appearing at heights of up to nearly 1,000 kilometers or so, constitute a spectacular feature of the upper air. The typical auroras are most prominent in and near the polar regions, especially around latitude 67° north and south. They appear in a variety of forms, some of them quite breathtaking: long rays like searchlight beams, crowns of light, or a splendid many-colored curtain that seems almost to brush the earth. Auroral measurements indicate that these displays may be of colossal size—hundreds of kilometers in height and extent—and that they may move very rapidly. They are observed to shift from west to east and to occur often at the same time in the north and south.

Auroras are probably caused by radiation from the sun and space bombarding the atoms of the upper atmosphere, thus causing electrical and magnetic disturbances. This is especially the case when solar spots and flares are at a maximum. As a result, electrified particles—electrons, protons, and ionized atoms—move along the force lines of the magnetic field of the earth. Nitrogen and oxygen atoms are the chief source of the auroral lights. Hydrogen and sodium ions are also involved.

Other effects may be observed in the thermosphere. Airglow may be seen here. This is a faint luminescence caused by the reaction of the molecules in the air to radiation from the sun and perhaps other sources.

The exosphere (400 kilometers and higher). This, the outermost fringe of the atmosphere, extends into space and merges with the atmosphere and radiation of the sun. The gases are extremely thin. Hydrogen is the chief constituent. Ultraviolet rays fill the exosphere. Faint glows appear in the sky here. Known as *zodiacal light* and *gegenschein*, they are due to sunlight reflected from countless particles of meteoritic dust that swarm near the earth.

WEATHER

by Henry Lansford

There are many kinds of weather: hot and cold, wet and dry, fair and stormy, and so on. These result from different combinations of the atmospheric variables of temperature, pressure, wind, humidity, clouds, and precipitation. The weather has always exerted a powerful influence on human affairs, and for centuries men have studied the atmosphere and tried to understand its behavior.

Meteorology is the branch of science that deals with the study of the atmosphere, or envelope of air that surrounds our planet. *Weather* is the state of the atmosphere, with regard to precipitation, wind, temperature, and other factors. Atmospheric changes that are the bases for weather are powered by energy from the sun, radiated across 150,000,000 kilometers of space. This energy warms the oceans and the land, which release heat into the air to drive the atmospheric motions that bring us our weather.

The short-term variations in the behavior of the atmosphere that we call weather are closely related to our day-to-day living. The rain that waters our crops and fills our reservoirs is part of the weather. So are the hurricanes and tornadoes that damage our cities, and the bolt of lightning that may strike us without warning.

In the beginning, people simply observed the weather. Then they began to try to use their observations as a basis for predicting what the weather would do next. But they eventually learned that they could not forecast the weather very successfully without understanding how it worked. And finally, as they gained some understanding of atmospheric processes, people began to think of trying to change the weather. These are the topics that we shall consider: man's efforts to observe, predict, understand, and change the weather.

MAIN INGREDIENTS OF WEATHER

Weather occurs in the *troposphere,* the thinnest and lowest layer of the atmosphere. The troposphere extends about 10 kilometers above the earth's surface at the equator. It thins down toward the north and south poles.

The air in the troposphere is very dense, composing about 80 per cent of the total weight of the atmosphere. The troposphere contains nearly all of the water vapor in the atmosphere. From the earth's surface to the upper limit of the troposphere, known as the *tropopause,* the temperature of the air decreases as the altitude increases.

The three main ingredients of the weather are sun, wind, and water. The sun supplies the energy that drives the winds. This energy is vast. The solar energy that falls on our planet in a single week is greater than the total energy produced by all the coal, gasoline, and other fuels that man has ever burned.

When it reaches the earth's atmosphere, much of this radiant energy is reflected and scattered. But part of it passes through the atmosphere. It strikes the earth's surface and is absorbed by the land and the oceans. These radiate much of the energy back into the atmosphere as heat. In the long run, our planet radiates the same amount of energy back into space as longwave heat energy as it receives in the form of shortwave solar radiation. If it didn't, our climate would grow much warmer or colder over the years, whereas it actually stays about the same.

But the earth absorbs more energy near the equator, where the sun's rays strike directly, and radiates more energy back into space at the north and south poles, where the solar radiation strikes at a shallow angle. Thus energy must somehow be transported from the equatorial to the polar regions. This transfer of energy is performed by the process of *convection.* In this process, a fluid—in this case, air—is heated, and the heat is transported by mo-

tions of the fluid. In our atmosphere these motions of air are the winds.

Wind is more than just a single feature of the weather. It occurs on every scale from global air currents, such as the trade winds and the westerlies, down to local winds, such as sea breezes. There are three scales of atmospheric motion, and all are major factors in determining what kind of weather occurs in a particular place at a particular time.

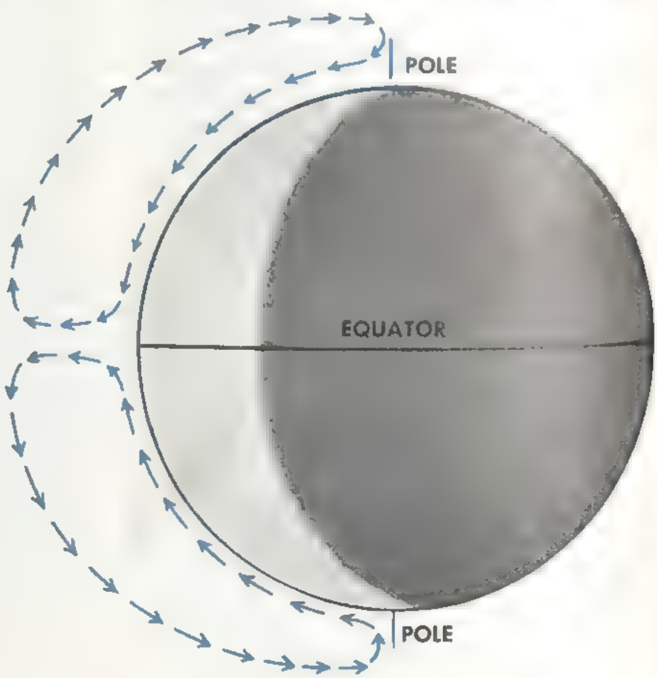
GENERAL CIRCULATION OF THE ATMOSPHERE

The largest scale of atmospheric motion, the *general circulation*, is the basic mechanism for transporting energy from the equator toward the poles. If the earth did not rotate, if it had a uniform surface—all ocean or bare, level land—and if solar energy arrived with equal intensity all around the equator, the general circulation would be very simple. Warm, light air would rise over the tropics. Cool, heavy air would move in from north and south to replace it. A pattern of circulation would form with high-tropospheric air moving toward the poles, and low-altitude air moving toward the equator.

But in reality it's not that simple. The earth does rotate; its surface is divided between irregular landmasses and oceans; and the input of solar energy to different regions varies with the days and the seasons.

The general circulation begins along the equator, where warm air rises in strong updrafts. This creates a belt of low atmospheric pressure at the equator. As the rising tropical air starts to pile up at high altitudes, it spreads to the north and south. In both the northern and southern hemispheres, at latitudes of about 25 to 30 degrees, part of the air starts to descend, producing regions of high pressure known as *subtropical high-pressure belts*. These belts are often called the *horse latitudes*. The descending air divides when it reaches the surface. Part goes back toward the equator and part continues toward the poles, thus creating two great bands of surface winds.

As these winds move north and south, the earth's rotation, through an effect known as the *Coriolis force*, twists them to the right in the northern hemisphere and to the left in the southern. Thus the winds blowing toward the equator move from the northeast in the northern hemisphere and



Theoretical circulation of the atmosphere from the equator toward the poles and from the poles toward the equator. The flow of air would be upward near the equator, poleward at upper levels and toward the equator at lower levels.

from the southeast in the southern hemisphere. These winds are called the *trade winds*. The region along the equator where they converge, or come together, is known as the *intertropical convergence zone*.

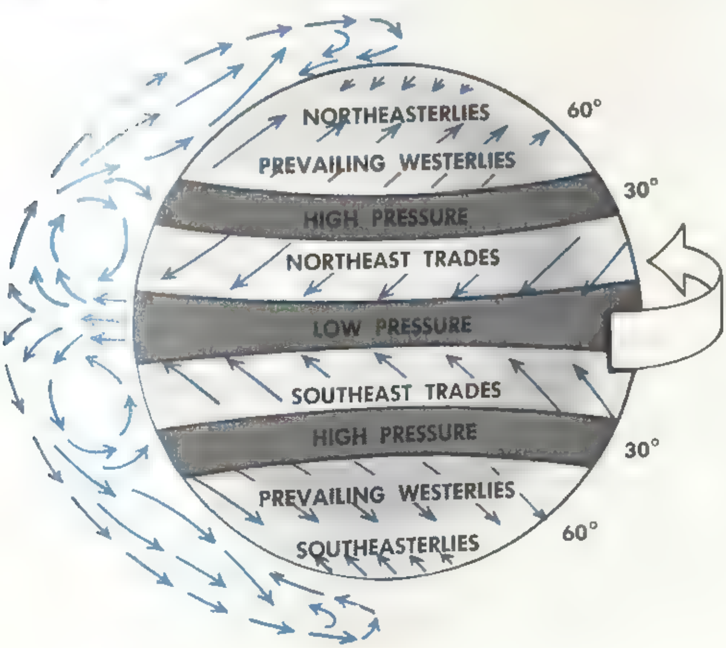
The winds that move poleward from the horse latitudes are also twisted by the earth's rotation, and they become the *prevailing westerlies*, or *antitrades*. Most of the United States is in the path of the prevailing westerlies, which produce our normal west-to-east movement of weather. In the southern hemisphere, at latitudes around 40°, there is not much land to drag at the moving air and slow it down. The strong westerlies that blow over the oceans in this region have given the region the nickname "roaring forties."

Other bands of prevailing winds are the *polar easterlies*. They are produced when the remaining high-level, poleward-moving air cools off and descends over the north and south poles. As it moves back toward the equator, this bitterly cold air is deflected westward to produce the polar easterlies.

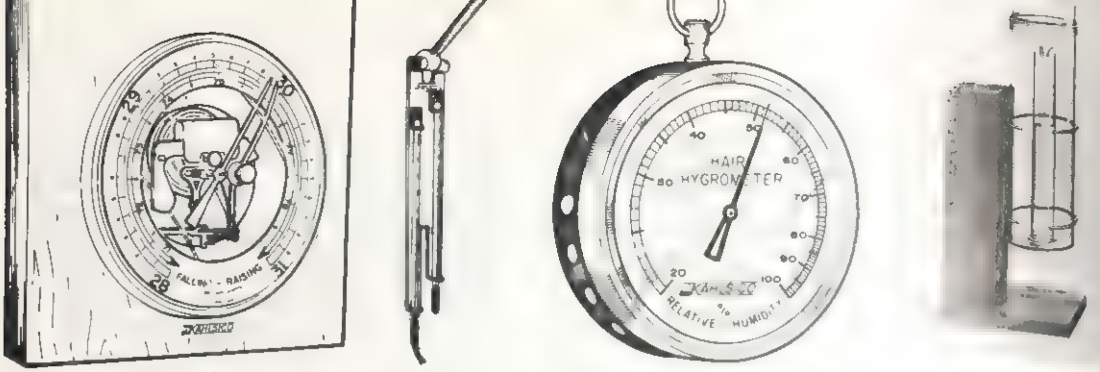
The vertical and horizontal motions of the general circulation create weather patterns that prevail in certain regions of the world. For example, the equatorial region is known not only for its lack of winds, but also for its regular and heavy rains. The Amazon River basin of South America, straddling the equator, often has close to four and one-half meters of rain a year.

This rain is caused by one of the fundamental principles of atmospheric behavior: rising air produces clouds and precipitation. As air near the surface is heated, it expands and grows less dense. This causes it to rise, and it continues to expand as it rises to higher altitudes. One of the basic laws of physics is that an expanding gas grows cooler. Cool air can hold less water vapor than warm air. The water vapor in the rising air begins to condense into cloud droplets, which eventually form raindrops. Thus a region of constantly rising air, such as the one along the equator, is very rainy.

Conversely, when the vertical motion of the air is consistently downward, fair weather is the rule, and rain falls infrequently. The deserts of the U.S. Southwest, the Sahara, and many other arid areas of the world are located in the high-pressure belt of the horse latitudes. Of course, many other factors besides the general circulation affect local weather and climate.



Distribution of the more or less steady, large-scale movements of winds over the earth's surface. An account of the different belts named here is given in the text. The broad arrow shows the direction in which the earth rotates.



Left to right aneroid barometer, sling psychrometer, hair hygrometer, and rain gauge. These instruments are used to measure atmospheric pressure, relative humidity, humidity, and the amount of precipitation, respectively.

Another cause of large-scale patterns of prevailing weather is the contrast between the rates at which land and ocean absorb and radiate energy. Landmasses heat and cool rapidly, while oceans gain or lose heat slowly. This is what causes *sea breezes*. The land heats rapidly, causing the air above it to expand. This produces a low-pressure area, and cooler air blows in from the sea to fill it. At night, the land cools more rapidly than the sea, and the wind turns to blow out to sea from the shore.

The world's largest landmass, Asia, produces the *monsoon*, a wind that is much like the sea breeze, except that it is on a larger scale and reverses with the seasons instead of the day and night. In winter the air over Asia grows cool and dense, and spreads toward the Indian and Pacific Oceans, producing the winter monsoon and fair weather. When spring comes, the air over the land becomes hotter and lighter, and the wind sweeps inland. The summer monsoon brings in moist air to produce torrential rains – more than seven meters per year in some mountain areas of India.

CYCLONES AND ANTICYCLONES

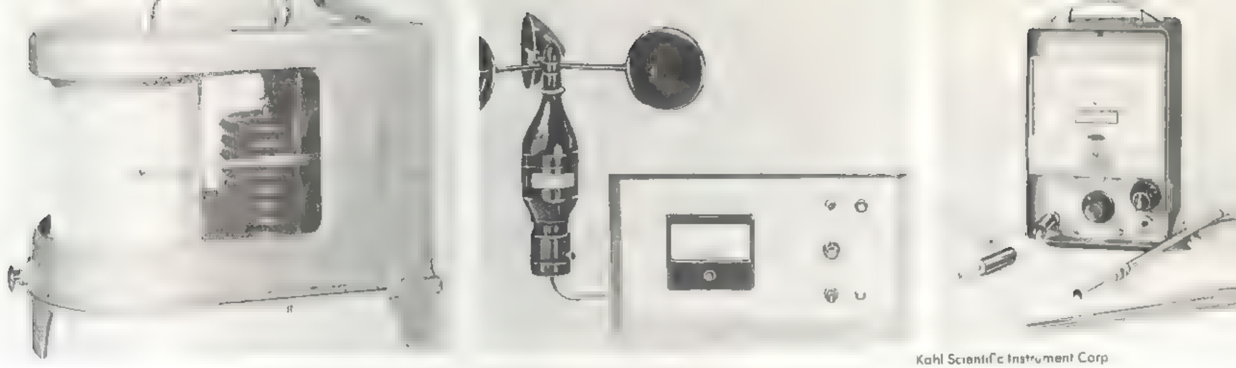
The second scale of atmospheric motion, smaller than the general circulation but still enormous by human standards, is the *synoptic*, or *cyclonic*, scale. Motions on this scale are characterized by rotating weather systems, hundreds of kilometers across, known as *cyclones* and *anticyclones*.

Cyclonic-scale weather systems cause the pattern of alternating good and bad weather that is characteristic of most of the United States and other areas in the north temperate zone. Cyclones and anticyclones are produced by the battle that rages when dissimilar air masses collide. These collisions occur in the region that is influenced both by the prevailing westerlies and the polar easterlies.

For example, a great mass of moist, light, tropical air may be carried north by the westerlies and collide somewhere over Kansas with a mass of cold, dry, heavy air brought down from Canada by the polar easterlies. One of these air masses usually will be moving with more force than the other one. If the cold air pushes in under the warm mass, lifting it up, the line where they meet is called a *cold front*. If the warm air mass moves into an area occupied by cold air, the line of collision is a *warm front*. In either case, the usual result is bad weather. Cold fronts often bring thunderstorms, tornadoes, and other violent weather phenomena. Warm fronts usually produce cloud cover and steady rain.

Along strong, active fronts, the air currents in the two masses usually move in opposite directions. Twisted by the earth's rotation, these winds may start to rotate counterclockwise, spiraling inward toward a center of low pressure. Around a center of high pressure, the winds will move outward and will rotate clockwise.

The counterclockwise weather system, circling around a low center, is a *cyclone*, sometimes called a *low*, or *depression*. The clockwise system is a *high*, or *anticyclone*. These great disturbances, traveling along one after another across North America, bring us our normal pattern of several days



Kohl Scientific Instrument Corp

Left to right: Barograph, an instrument that measures and records atmospheric pressure; cup anemometer, an instrument to measure wind velocity; constant temperature hot wire anemometer, also used to measure wind velocity.

of bad weather alternating with several days of good weather.

LOCAL WEATHER

Weather on the third, or local, scale is much more sudden and unpredictable than it is on larger scales. The thunderstorm, for example, that rains out a picnic or ball game can grow very suddenly. Thunderstorms are produced by rising air, and often are associated with cold fronts. However, a front is not a prerequisite for thunderstorm development. An unstable situation, the first requirement for thunderstorms, can be created by local differences in the earth's surface. On a bright summer day the air over an open field will be heated more than the air over surrounding forests. The warm air, expanding and growing lighter, will start to rise. If the air is moist enough, its water vapor will begin to condense into cloud droplets. The change of state from vapor to liquid releases more heat, strengthening the upward motion. If conditions are right, a cumulus cloud will form and grow into a cumulonimbus, or thunderhead. If the growth process is strong and sustained, the thunderhead can produce torrential rain, thunder, lightning, and hail, and can create quite an uproar, on a local scale, during its life cycle of a few minutes or hours.

INSTRUMENTS USED TO OBSERVE THE WEATHER

Before man could begin to understand the workings of the weather, he had to learn how to observe its component parts. Even while they blamed changes in the weather on the whimsical notions of their fickle gods, the ancient Greeks began observing the weather. By the fifth century B.C., they were recording wind information and displaying it publicly for the benefit of seafaring men. But for the next 20 centuries or so, weather observation did not progress much beyond noting the direction of the wind, and measuring the amount of rain that fell.

Galileo's invention of the thermometer in the seventeenth century opened a new era in observation. A few years later, his pupil Evangelista Torricelli invented the barometer, a scale used to determine atmospheric pressure. During the next 200 years, instruments were devised for measuring wind speed and humidity. Now man could observe the basic ingredients of the weather: temperature, pressure, wind, humidity, clouds, and precipitation. Today these are still the observations that are of primary interest to meteorologists.

A standard surface weather station, set up to make ground-level observations of atmospheric conditions, uses essentially the same instruments that have been used to observe the weather for hundreds of years. Weather stations, most maintained by national weather services such as the United States National Weather Service, are located about 300 to 800 kilometers apart over much of North America, Europe, and Asia. Over other land areas, and over the vast expanses of the oceans, weather observations are in very short supply, although ships and airplanes gather some weather data.

Air temperature is usually measured with a *thermometer* located in a shelter

about one and one-half meters above the ground. The thermometer shelter is built so that air can circulate through openings in the sides. It is painted white to prevent overheating by the sun. Observations are sometimes made with a simple mercury thermometer, read by an observer who writes down his readings. Some weather stations use a *thermograph,* which makes its own continuous record of temperature fluctuations. Most thermographs use a bimetallic strip made of two different metals that expand at different rates when they are heated. As this strip heats and cools, it bends to one side or the other. A pen connected to the strip traces a line on a moving paper chart, making a permanent record of variations in temperature.

The *mercury barometer* is a glass tube closed at the top and open at the bottom. The tube is filled with mercury, and the open end is placed in a dish of mercury. The height of the mercury in the tube, held up by the pressure of the atmosphere, will stand at about 76 centimeters. But the height of the mercury in the column varies slightly with the atmospheric pressure. Thus it is an index to changes in the atmospheric pressure. Another instrument for measuring atmospheric pressure is the *aneroid barometer,* a flat metal container with most of the air pumped out of it. The container expands and contracts with changes in atmospheric pressure, moving a pointer on a dial. If it is fitted with a pen and strip-chart recorder, the aneroid barometer is known as a *barograph.*

Wind direction is observed with an age-old device, the *wind vane.* This is a horizontal rod, pivoted near its center, with a vane, or tail, at one end and a pointer at the other. The wind blows the vane around to the downwind direction, so that the pointer indicates the direction from which the wind is blowing.

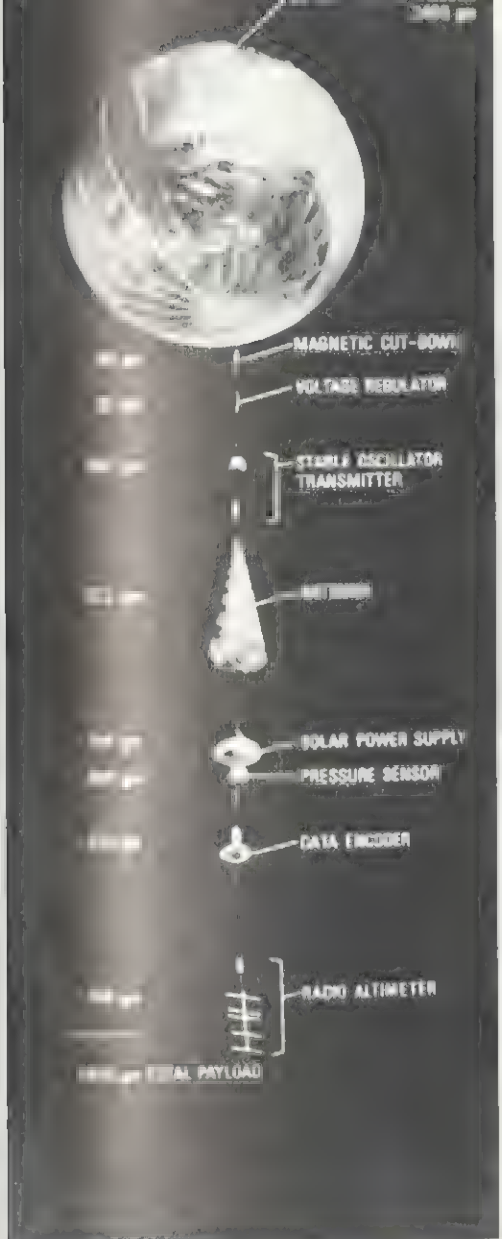
Wind speed is measured with an *anemometer.* The simplest anemometer is a flat plate hanging from a hinge at the top. The plate is turned to face the wind, and the angle at which the plate hangs as it is pushed back by the wind indicates the speed of the wind. A more common type of anemometer has three or four cups mounted on arms attached to a rotating shaft. A device similar to a car's speedometer converts the speed of rotation into a wind-speed reading. The wind vane and anemometer can be connected to a recorder to provide a record of wind speed and direction.

Humidity, the amount of water vapor in the air, can be measured with a *hygrometer,* which uses a filament of some material that lengthens and shortens as its moisture content changes. The first hygrometer, built by the Swiss scientist Horace de Saussure in 1790, used a strand of human hair connected to a pointer. Relative humidity, the ratio of the amount of water vapor actually in the air to the maximum amount that it can hold, is often measured with a *sling psychrometer.* This device consists of a pair of thermometers mounted in a metal frame that can be whirled or slung through the air. One of the thermometers has a small piece of cloth wrapped around its mercury bulb. When this cloth is soaked with distilled water, and the psychrometer is whirled around, the evaporation of water from the cloth cools the wet-bulb thermometer. The observer reads both the wet-bulb and dry-bulb thermometers, and uses psychrometric tables to obtain a value for relative humidity.

CLOUD OBSERVATION

Clouds are observed by eye and classified according to an international system worked out in the early nineteenth century by Luke Howard, an English chemist. He divided clouds into three broad groups. *Cirrus* clouds are high, wispy streaks of cloud composed of ice crystals. *Stratus* clouds are broad sheets that often bring steady rain. *Cumulus* clouds are the flat-based, puffy clouds that sail across summer skies. Our modern cloud-classification system includes many combinations and subdivisions of these three basic categories.

When a meteorologist refers to precipitation, he means rain, snow, or any form of liquid or solid water that precipitates, or falls, from the sky. The simplest form of precipitation gauge is a straight-sided container, with a scale, or ruler, for measuring



NOAA

This balloon is an instrument platform that will transmit information on weather to a meteorological research satellite for processing.

the depth of the water that falls into it. Most rain gauges funnel the water into a narrower tube to permit more accurate measurement of small amounts of precipitation. Like other weather instruments, rain gauges can be built to record their measurements continuously.

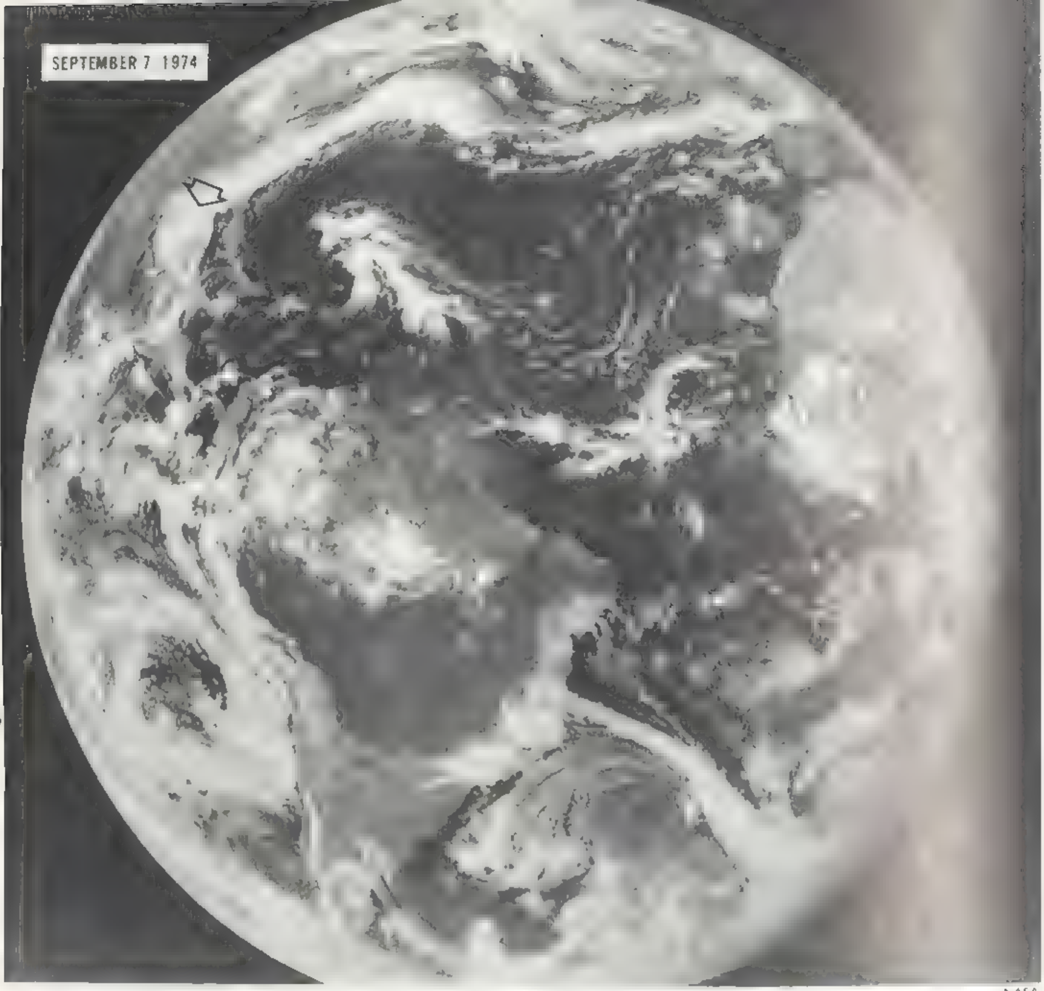
WEATHER BALLOONS

Modern meteorologists are not satisfied with knowing conditions just at the earth's surface. They also need to know what's going on at many different levels of the atmosphere. One way to sound the atmosphere is with balloons filled with hydrogen or helium gas. Such balloons rise when released. The simplest form of weather balloon is the *pibal*, or pilot balloon. This is a rubber balloon that is tracked from the ground with an optical instrument called a *theodolite*. The balloon's flight path indicates the direction and velocity of the winds that it encounters.

A more sophisticated weather-balloon system is the *rawin*, or radar winds. The rawin uses radio equipment to track the balloon as it rises. Observations can continue even if the balloon disappears from sight into clouds. Since the late 1940s, observations of conditions in the upper atmosphere have been made regularly at many weather stations by *rawinsondes*, or radar wind soundings. The balloon carries a radiosonde, or radio sounding package, which contains sensors to measure temperature, pressure, and humidity, and a radio transmitter to send the readings back to the ground.

Radar has proved to be a valuable tool for observing the weather. A radar station transmits a beam of radio energy through the atmosphere. When the beam strikes an object, part of the energy is reflected back to the station, where it is picked up by a receiver. Each of these contacts of the radar beam with an object can be displayed as a "blip," or bright spot, on a screen at the radar station. Radar has proved very useful in locating and tracking storms. Radar observations first indentified an important feature of hurricanes: the rainbands that spiral into the center, or *eye*, of the storm.

A new type of weather balloon may do a great deal to fill some of the gaps in our global weather observations. Known as constant-density-level balloons, these plastic spheres are designed to stay in the air for months, instead of the minutes that it takes a rawinsonde to make its sounding. Instead



NASA

NASA's Synchronous Meteorological Satellite took this photo showing hurricane Carmen striking the Gulf Coast of the United States in September 1974.

of making a quick vertical ascent, constant-density-level balloons are designed to settle down at a predetermined level and to rove about the earth, sending back weather data from wherever they wander. An operational system, which lies in the future, would include satellites to relay the data from several thousand constant-density-level balloons, as well as from ocean buoys and other unmanned weather stations, back to a ground station. Scientists from the U.S. National Center for Atmospheric Research (NCAR) have been testing constant-density-level balloons known as GHOST (Global Horizontal Sounding Technique) balloons in the southern hemisphere for several years. French scientists are testing a similar system, known as EOLE, in the southern hemisphere.

WEATHER SATELLITES

Weather satellites are a new tool that is filling in many of the great blank spaces on the global weather map. In April 1960 the United States launched the first Tiros (television infrared observational satellite) into orbit around the earth. This drum-shaped spacecraft was equipped with a television camera that scanned the earth's surface and sent back pictures of our planet's cloud cover. For the first time, man was able to see whole large-scale cloud systems, instead of just the bits and pieces that can be seen by a ground-based observer.

The first Tiros satellites were experimental, but in 1966 a working weather-satellite system became a reality. Tiros satellites were improved and followed by other

weather satellites. The latest in the U.S. family of weather satellites is the SMS, or Synchronous Meteorological Satellite, series, the first of which was launched in 1974. These craft are placed in an orbit that keeps them positioned above one spot on the earth's surface. They thus can observe and monitor changing weather conditions in a single area for an extended period of time.

Nations other than the United States are also working with weather satellite systems. The Soviet Union, for example, has launched a series of Cosmos and Meteor weather satellites and, in a joint project with some other countries, an Intercosmos weather satellite.

PREDICTING WEATHER

To many people, a meteorologist is a weather forecaster. Although weather forecasting is only one application of meteorology, it is the one that most frequently touches the day-to-day affairs of people.

About 300 B.C. an ancient Greek naturalist, Theophrastus, wrote a book that would be the basic text for weather forecasting for 2,000 years. Called the *Book of Signs*, it was simply a collection of more than 200 natural signs that Theophrastus thought were significant indicators of the kind of weather that was on the way. Some of these signs are still part of the folklore of weather. The old jingle "Red sky at morning, sailor take warning/Red sky at night, sailor's delight" may be found, in more prosaic language, in the *Book of Signs*.

For many centuries, weather forecasting remained on this basis. Many unrelated signs were used to predict apparently unrelated weather phenomena, but no theories were proposed to account for all the phenomena as part of a great system.

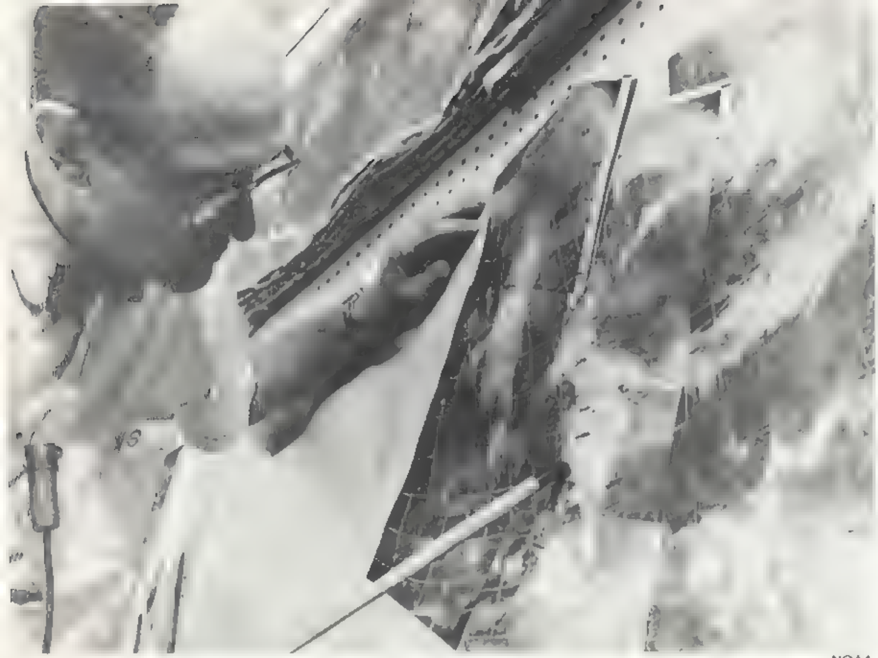
In the seventeenth century, as we have mentioned, new weather instruments began to appear, and man learned to measure other atmospheric variables besides wind direction and rainfall. Once men began to keep regular, accurate records of temperature, humidity, and barometric pressure, as well as of winds and precipitation, the foundation was laid for scientific weather forecasting.

By the mid-eighteenth century, men were beginning to understand that the weather in a particular location was not an isolated occurrence, independent of the weather in other places. Benjamin Franklin discovered an important principle of weather quite by accident. He observed a violent coastal storm in Philadelphia on October 21, 1743, with winds from the northeast. Assuming that the storm had come from the northeast, he was surprised to learn that a storm, apparently the same one, had hit Boston the next day. This was an important clue to the nature of cyclonic storms: the winds within the storm do not necessarily blow in the direction of travel of the storm. Today we know that such storms actually rotate around a low-pressure center.

By the middle 1800s meteorologists understood that weather systems grow in the atmosphere as they move across the face of the earth. But this knowledge did not have much practical use as long as weather information could travel no faster than the weather itself. The invention that marked the beginning of real weather forecasting was the telegraph. The first telegraph lines were strung in 1844 between Baltimore and Washington, D.C., and soon poles and wires started to go up all over the United States. By 1850, weather reports were being telegraphed to the Smithsonian Institution in Washington, D.C., from dozens of stations. The Smithsonian began

Certain weather conditions in which there is little air movement can result in a layer of pollution hanging over an area—in this case, Denver, Colorado—for a long period of time.

UPI



A meteorologist analyzes a cyclonic storm. A series of satellite photographs makes it possible to view the circulation pattern of a storm over large areas of the earth.

NOAA

publishing weather maps for the area covered by its network.

The first real weather forecasts in the United States, known then as "probabilities," were made by the Cincinnati Observatory. The first official government forecast was issued by the U.S. Army Signal Service, which set up a weather service to provide storm warnings for ships on the Great Lakes. During the last part of the nineteenth century, many other nations also established weather services.

Until the early 1900s, weather forecasting in the United States and Europe consisted mainly of watching the weather to see where storms were occurring, and assuming that these storms would move eastward. There were no precise theories of the formation, growth, and decay of weather systems.

NUMERICAL MODELS

One of the greatest contributions to modern weather theory was made by a group of scientists working at the Norwegian Geophysical Institute in the early twentieth century. This group, known as the Bergen School, was headed by Vilhelm Bjerknes, whose son Jakob was also one of the leading members of the group. Their most notable accomplishment was the development of the polar-front theory, which accounts for the birth of storms by collisions between cold and warm air masses.

But Vilhelm Bjerknes also proposed an approach to weather forecasting that is the basis for much of the theory and practice of meteorology today. In a paper published in 1904, Bjerknes suggested that weather forecasting could be considered "a problem in mechanics and physics." Stated simply, Bjerknes' proposition was that the atmosphere is a fluid, subject to the laws of physics. If the laws that govern atmospheric behavior could be expressed mathematically, it should be possible to begin with the present state of the atmosphere, expressed numerically, and simulate its future behavior with mathematical computations to predict future weather.

Modern meteorologists feel that Bjerknes was on the right track, but he was unable to develop the numerical techniques needed for a forecasting system. A few years later, an Englishman named Lewis F. Richardson came even closer to solving the problem. In a book published in 1922, Richardson proposed methods that are the basis of present-day numerical forecasting techniques. But Richardson was ahead of his time. To put his system into operation, he needed 2,000 weather stations located all over the earth, something that still doesn't exist. And to make his forecasts, he needed 64,000 mathematicians operating 64,000 calculating machines 24 hours a day.

It was not until the advent of the elec-

tronic computer that it was possible to test Richardson's theories and to discover that they were generally valid. In 1946 a group at Princeton University, headed by John von Neumann, used a computer called MANIAC (Mathematical Analyzer, Numerical Integrator, and Computer) to develop Richardson's proposals into working techniques.

Today, numerical techniques are used to make better forecasts of weather. Scientific groups in many countries are working toward the goal of computer-produced global weather forecasts that will be accurate for large-scale weather systems as much as two weeks in advance. Many problems must be solved before this goal is reached, and it may be many years before the two-week global weather forecast is a working reality. But many scientists are convinced that it is an attainable goal.

METEOROLOGISTS AT WORK

Today our weather forecasts can be accurate only about two days into the future. Even then they are subject to suddenly changing local conditions. Forecasts reach most of us by way of a television weatherman who may or may not be a meteorologist. Although an increasing number of radio and television stations are hiring professional metorologists, many of the present weathermen are simply reporters, presenting the weather as they would a news story.

Most of the meteorologists in the United States who are in weather-forecasting work are with agencies of the U.S. Government. The largest government weather-forecasting agency is the National Weather Service, with numerous branches. The U.S. Army, Navy, and Air Force have their own weather services to forecast weather for military operations. Airlines and other firms whose operations depend on the weather usually have their own meteorologists.

The center of the U.S. Weather Service's forecasting operation is the National Meteorological Center (NMC) at Suitland, Maryland. This center provides the basic weather analyses and forecast guidance used by the bureau's field offices in making their forecasts for the public. To provide the public with an overall picture of general weather conditions expected over a large geographical area about 48 hours in advance, the Weather Service operates 25 area-forecast centers. Each of these centers is responsible for an area that covers about two states. The area-forecast centers issue state forecasts every six hours, along with a discussion of the reasoning on which the forecast is based.

The state forecasts are used as a basis for zone forecasts for areas ranging from 13,000 to 38,000 square kilometers within which the weather is expected to be fairly uniform. Local forecasts, prepared by more than 200 Weather Service offices, include a detailed description of the weather expected in a town or city and an area, with a radius of about 40 kilometers, around it.

The Weather Service operates special centers for forecasting severe storms, such as tornadoes, and for hurricane warnings. The bureau also makes specialized forecasts of air-pollution potential, high water, killing frosts, and other weather or weather-related phenomena that are vital to people in certain areas of the country.

INTERNATIONAL PROGRAMS

Two international programs now under way are aimed at increasing man's knowledge of the atmosphere on a global scale. The first of these, the World Weather Watch (WWW), is coordinated by the World Meteorological Organization (WMO), a United Nations agency. The World Weather Watch, operated by the national weather services of WMO member nations all over the world, is designed to improve operational weather forecasting, using techniques that have been tested and proved practical. Present observations include surface observations, rawinsonde data, and satellite pictures. Systems that probably will be utilized once they become operational include remote-sensing satellites to measure such things as temperature and water vapor, constant-density-level balloons, and other tools that are now under

development. Data from the worldwide observing network will go to three weather centers: one in Washington, D.C. in the United States; one in Moscow, U.S.S.R.; and one in Melbourne, Australia. Computers will be used to make large-scale forecasts.

The Global Atmospheric Research Program (GARP) is designed to gain the knowledge and develop the tools to make WWW effective. Numerical weather prediction on a global scale will never be feasible unless man learns much more than he now knows about large-scale processes in the atmosphere. Through a gradually expanding series of observational programs, conducted over comparatively short periods of time, GARP has attempted to define those processes.

These observational programs are starting in the tropics, where the whole global weather machine begins to operate. The first important tropical experiment, however, preceded the formal organization of GARP. It was the Line Islands Experiment, a program of intensive meteorological observations conducted in the spring of 1967 in the equatorial Pacific Ocean. This project involved scientists from nearly two dozen universities, government agencies, and other research groups.

A much larger experiment, and the first U.S. project to be a part of GARP, was conducted in the tropical Atlantic Ocean in the spring and summer of 1969. The Barbados Oceanographic and Meteorological Experiment was designed primarily to study heat exchange and other interactions between the tropical ocean and the atmosphere. A network of ships, planes, buoys, and other data-gathering devices, operating in the ocean east of the island of Barbados, measured heat exchange and other processes in a great parcel of the ocean and the atmosphere.

In 1974, 70 countries took part in another complex weather experiment. The project was known as GATE—GARP Atlantic Tropical Experiment—and involved research ships, weather balloons and satellites, and radar systems. The purpose of the study was to determine how atmospheric and oceanic conditions affect weather.

INFLUENCING THE WEATHER

Even before they had any real understanding of the mechanisms of the weather or had begun to observe it in any systematic way, people started trying to change the weather. Primitive people tried to make the weather cooperate by offering sacrifices to their gods, or by performing rituals such as rain dances, symbolizing the kind of weather that they wanted.

Later attempts at weather modification, although they were more scientific in terms of the knowledge of their time, were based on assumptions that we know today were erroneous. Many 19th-century rainmaking schemes used explosives, including rockets, artillery, and dynamite, to try to blast rain out of the sky. Other rainmakers proposed using great fires to create upward convection and produce rain, or using huge refrigerators to chill the air and force its moisture to condense.

A basic truth about weather modification finally emerged: most weather phenomena involve such vast amounts of energy that trying to alter them by brute force is an impossible task. The only way in which man is likely to influence the weather is by choosing situations where something is hanging in the balance, ready to go one way or the other. Then it may be possible to trigger a large-scale result with a small input of energy.

Most modern attempts at weather modification, whether aimed at rainmaking, increasing snowfall, or suppressing fog, hail, or hurricanes, use the technique known as *cloud seeding*. Cloud seeding is still not fully understood. It is based on the fact that atmospheric water often exists in the form of supercooled clouds, made up of tiny water droplets that are still liquid even though they are colder than 0° Celsius, the freezing point of water. If small ice crystals form in a supercooled cloud, they grow very rapidly, taking up the water droplets all around them. They soon become snowflakes heavy enough to fall from the cloud. In cold weather the crystals reach the ground as snow. In warm weather they melt and reach the ground as rain.

Cloud seeding is a technique for stimulating the formation of the first tiny ice crystals in a supercooled cloud. The first seeding experiments were performed in 1946 at the General Electric Research Laboratory. Experimenting with artificial clouds in a deep-freeze chamber, scientists discovered that putting dry ice into the cloud would trigger the freezing process and produce snow. Soon afterward they repeated the experiment with real clouds, using an airplane to seed the clouds with dry ice.

Then they discovered that crystals of silver iodide could also be used to seed clouds. Even though the silver iodide was not so cold as dry ice, it still produced snow. This apparently results from the similarity between the crystal structure of silver iodide and that of ice.

Today, although weather modification is a controversial subject among meteorologists, it does appear that cloud seeding can be used effectively to change the weather. Under certain conditions, it can be used to trigger rain in convective storms. It can be used in orographic snowstorms, produced when moist air is forced upward as it flows across high mountains, to increase snowfall. It can be used on potential hailstorms to make the moisture in the storm cloud fall as small hailstones or rain rather than growing into large, dangerous hail.

But none of these applications of cloud seeding have been tested and developed to the point that they can be done to order, with consistently effective results. Much more laboratory research and field experimentation needs to be done before we can hope to modify the weather intelligently.

POLLUTION AND WEATHER

Another kind of weather modification that is receiving increasing scientific attention is inadvertent modification, or changes in the weather that are produced unintentionally. Such changes can be caused, for example, by large cities with many factories. The heat, moisture, and pollution thrown up into the atmosphere by the smokestacks can produce rain, hail, and other bad weather in areas downwind from the city.

NOAA

The construction and use of weather maps is an important part of weather analysis and forecasting. Here, a scientist determines the area where a tornado may occur

On a larger scale, we may be changing weather and climate by altering the amount of energy that enters and leaves our atmosphere. Dust and other substances, collecting in a layer high in the atmosphere, can stop some of the solar radiation from entering the atmosphere. If this continues over a long period of time, the result could be a gradual decrease in our average temperature. The result could conceivably be a new ice age.

On the other hand, an increase in carbon dioxide in the atmosphere could cause a warming trend, as carbon dioxide acts like the glass roof of a greenhouse, letting the sunlight in but holding the heat inside. Carbon dioxide is a by-product of industry, and some scientists have conjectured that continued industrial use of coal, oil, and other fossil fuels could produce a gradual warming. This might slowly melt the polar ice caps, raising the oceans and flooding many of our coastal cities.

These predictions are little more than guesses, as man does not know enough about large-scale, long-term atmospheric processes to predict the effects of man-made changes such as increased dust or carbon dioxide. But the predictions do emphasize one very important point: man must learn a great deal more than he now knows about the weather and other atmospheric processes and phenomena if he is to avoid making some serious mistakes.

WIND

by Ivan R. Tannehill

Everyone realizes that the air circulates in the form of breezes, eddies, variable winds, hurricanes, and so on. The importance of this circulation, however, is not so well known. It is not simply a single feature of the weather, such as sunshine or sleet. Rather it is largely responsible for all weather changes. It may produce clouds that veil from us the sun by day and the stars by night. It may bring snow, rain, hail, droughts, or floods.

The air in motion affects the distribution of the world's population and the character of its civilization. In regions where the winds are favorable at the proper seasons, agriculture and industry flourish and people prosper. In other areas, where the winds are too cold or too dry, there are frozen or desert wastelands. The circulation of the air (in the form of monsoon winds) brings rain to densely populated regions of China and India, while at approximately the same latitudes it denies moisture to the vast deserts of northern Africa.

WHY AIR CIRCULATES

The circulation of the air is due partly to the effects of solar radiation. The sun's rays do not heat the air very much as they pass through it on their way to the surface of the earth. The air is warmed chiefly by the heat that is radiated back from land and sea. Air circulation is also brought about in part through the force of gravitation. The effects of gravitation upon air masses depend upon the degree to which these masses have been heated.

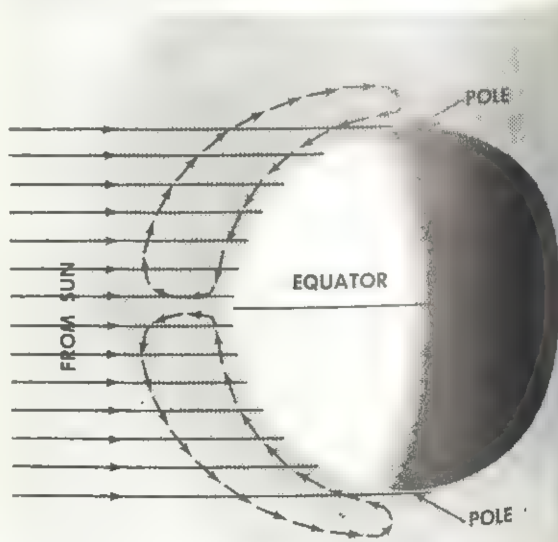
When air is heated, it expands. Since a cubic meter of warm air is less dense than the same bulk of cold air, it exerts less pressure. The warm, low-pressure air at the surface is hemmed in on all sides by colder, denser, high-pressure air. The atmosphere becomes less dense the higher up one goes. The warm air, following the path of least resistance, makes its way upward in the atmosphere. This fact causes the formation of clouds, which in turn may yield rain, snow, hail, or sleet. The rising air currents carry water vapor, which is a gas, up into the higher levels of the atmosphere. Here the water vapor is converted into droplets and becomes visible in the form of clouds.

The atmosphere is not uniformly heated because the rays of the sun do not strike all parts of the earth's sphere at the same angle. They strike the earth's surface at the equator, on the average, more vertically than in any other region of the earth. Hence the air is heated most effectively in the vicinity of the equator.

THEORETICAL MODEL

Suppose that the earth's surface consisted entirely of water and that the earth did not rotate on its axis nor move around the sun, but rather hung motionless in space. Suppose, too, that the earth and the

Theoretical circulation of the atmosphere, assuming that the earth's surface consists entirely of water and that the earth neither revolves around the sun nor rotates. Actually, the atmospheric circulation is complicated by many factors, which are described in the text.



sun remained forever in the relative position they occupy at the equinoxes—about March 21 and September 23—when the sun's rays strike perpendicularly at the equator. This is roughly what would happen in the regions exposed to the sun.

The air would be effectively warmed by the sun at the equator and it would rise. This would bring about a region of low pressure at the lower levels of the atmosphere at the equator. As the air would rise, it would produce greater pressure at the upper levels in the vicinity of the equator, because the weight of the rising air would be added to the weight of the air already in that particular area.

Farther north or south, the sun's rays would strike more obliquely. As a consequence, the surface of the water would not be heated so much and it would not heat the air so thoroughly. Therefore the air would not rise so rapidly, and the pressure in the upper areas would not be so great as at the equator. The air would be heated least of all at the north and south poles and would rise least of all. Naturally the pressure higher up in the atmosphere would also be the least of all.

The result of all this would be a kind of pressure slope aloft from the equator to the poles. This slope would be highest at the equator and lowest at the poles. To the upper air at the equator, as we have seen, would be added new supplies of warm air from the surface of the water. The air would then flow down the pressure slope toward the poles and would set up a constant circulation in that direction.

There would normally be a high-pressure area at low atmospheric levels at the poles, since the cold air in that region would tend to hug the surface. To this cold air at the poles would be constantly added the air circulating from the equator. Equatorward from the poles, the pressure of the air at the surface would constantly decrease as more of the air would be warmed and would be carried to higher levels. Hence the accumulated air at the poles would begin making its way to the regions of less resistance in the direction of the equator. There would be a circulation at the surface away from the poles and toward the equator. When the air masses from the poles would reach the equator at last, they would be heated with the rest of the surface air and would rise to higher levels in the atmosphere. They would make their way down the pressure slopes to the poles as before.

EFFECT OF LAND AND WATER AREAS

The actual circulation of the air is not nearly so simple as this description would make it appear. It is true that in many areas there is a general drift toward the poles in the upper air and a general drift toward the equator at the surface. But the circulation is affected by a number of important factors.

For one thing, the surface of the earth is not a continuous expanse of ocean. It is made up of land and sea areas. These are not equally heated by the rays of the sun, and such differences in heating are heightened by the alternation of day and night and of the four seasons.

Water warms more slowly than land. It also cools more slowly. There are several reasons why this is so. The water reflects more of the sun's rays than it absorbs. The rays that are absorbed penetrate the water to a considerable depth and are not concentrated at the surface. The colder water from the lower depths of the sea is constantly being mixed with the warmer water at the surface through the churning action of the waves. Again, evaporation is always taking place at the surface. Evaporation has a cooling effect. Water is a poor radiator of heat. Once it has been warmed, it has a tendency to retain heat for a considerable period of time.

The land does not reflect the rays of the sun to any considerable extent; it absorbs most of them. The rays do not penetrate far beneath the surface. Hence the land surface effectively collects the sun's heat and rapidly becomes warm. It stores very little of this heat, but radiates it away rapidly. Therefore, it loses heat quickly at night and in the winter. That is why temperatures on land often show striking extremes. The highest and the lowest temperatures on earth are to be found in land areas. In these areas, too, we find the wid-

est temperature range. The average annual range is less than 3° Celsius over the ocean at the equator. It is about 65° Celsius in certain regions of the Soviet Union.

The effects of the varying temperatures of land and sea are clearly seen in the case of sea and land breezes. In the daytime, the land, warming quickly, becomes more heated than the waters offshore. The warm air rises rapidly and is replaced by the colder air flowing in from the sea. Hence the surface winds blow from the sea to the land by day, and we have sea breezes.

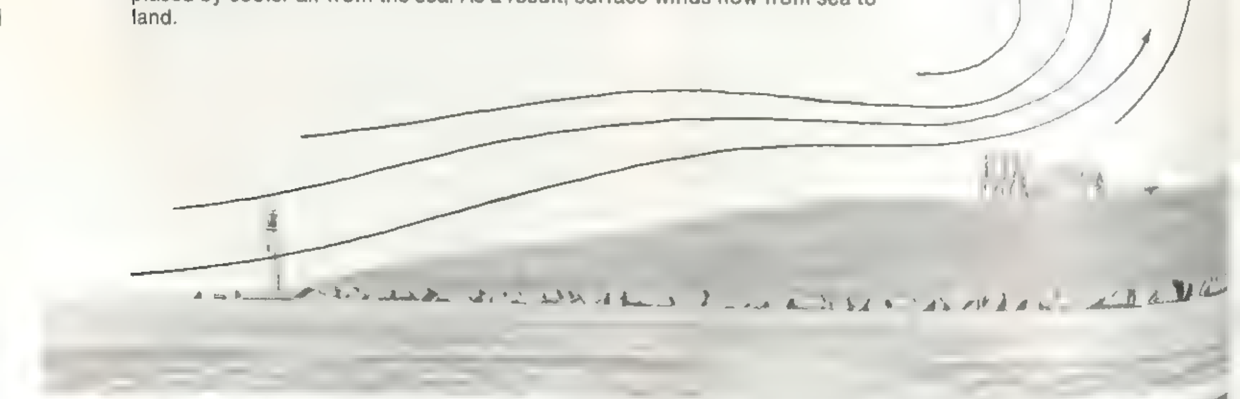
At night, the land cools quickly, while the sea retains most of its heat, so that now it is warmer than the land. The warm air, therefore, rises over the sea and is replaced by the cooler air from the land. Consequently surface winds blow from the land to the sea at night, and we have land breezes.

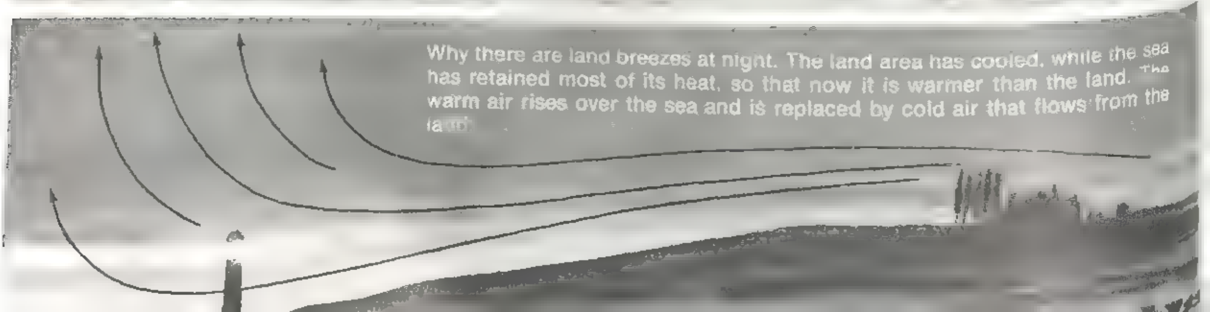
We find much the same situation on a grander scale on the continent of Asia and the nearby seas. The interior of the great Asian landmass becomes heated in the summer. Its atmosphere expands and flows outward aloft. A great low, or low-pressure area, develops, and moist air flows inland from the comparatively cool oceans to the east and south. This produces the seasonal wind called the *summer monsoon.* "Monsoon" comes, by way of the Portuguese, from *mausim*, an Arabic word meaning "season." In winter, the interior of Asia becomes colder than the seas to the east and south, and a vast high, or high-pressure area, develops. The air over the seas, warmer than the land air, rises rapidly and is replaced by air from the land. Therefore dry, cold winds blow seaward, producing the *winter monsoon.*

In other areas, too, highs and lows of vast extent develop because the oceans differ in temperature from the surrounding landmasses. For example, the northern oceans are relatively warm in winter. Hence they are the seats of two great lows, one centered near Iceland and the other near the Aleutian Islands off the coast of Alaska.

Thus the circulation of the air is affected by the relative temperature of the land and water as day alternates with night, and the four seasons alternate. The circulation is also profoundly influenced by the rotation of the earth.

Why there are sea breezes during the day. The land warms quickly and becomes more heated than the offshore water. As the warm air rises, it is replaced by cooler air from the sea. As a result, surface winds flow from sea to land.





Why there are land breezes at night. The land area has cooled, while the sea has retained most of its heat, so that now it is warmer than the land. The warm air rises over the sea and is replaced by cold air that flows from the land.

EFFECT OF ROTATION

Because of its rotation, the earth acts like a great turntable, sliding from under any air that is moving over its surface. To an observer facing the direction of the equator, the effect of this turntable is such that the wind, whatever the direction of its motion, is turned to the right in the Northern Hemisphere and to the left in the Southern.

EFFECT OF LANDSCAPE

The circulation of the air is also affected by mountains, hills, trees, buildings, and other irregularities, natural and man-made upon the earth's surface. On a more or less level plain, where such obstructions are fewest, the winds sweep across the surface of the earth with the greatest regularity. Within a big city, with its innumerable buildings of different heights, the force of the winds is broken and there are many eddies. The higher above the earth's surface the winds are, the less they are affected by the features of the landscape.

The friction that air motion meets at the earth's surface causes eddies and other irregularities, which are called *turbulence*. The erratic course of smoke pouring from a chimney may follow a general direction, but it will continually swerve from it. Weather observers ignore turbulence in most calculations. They are interested in the average speed and direction of the wind and not in the innumerable deviations from that speed and direction. In aviation forecasts, however, turbulence is carefully indicated, for it is an important factor. It accounts for the existence of air pockets, which may cause an airplane to suddenly dip or rise, to the great discomfort of the passengers. In fact, if the turbulence is unusually severe, it may be dangerous.

MEASURING WIND

It is all very well to indicate in a general way, as we have done, the various factors that cause the circulation of the air to be what it is. We would not be able to study the winds effectively, however, unless we could determine accurately their direction and speed and the changes in atmospheric pressure caused by their circulation. Fortunately, a number of devices supply us with this essential information.

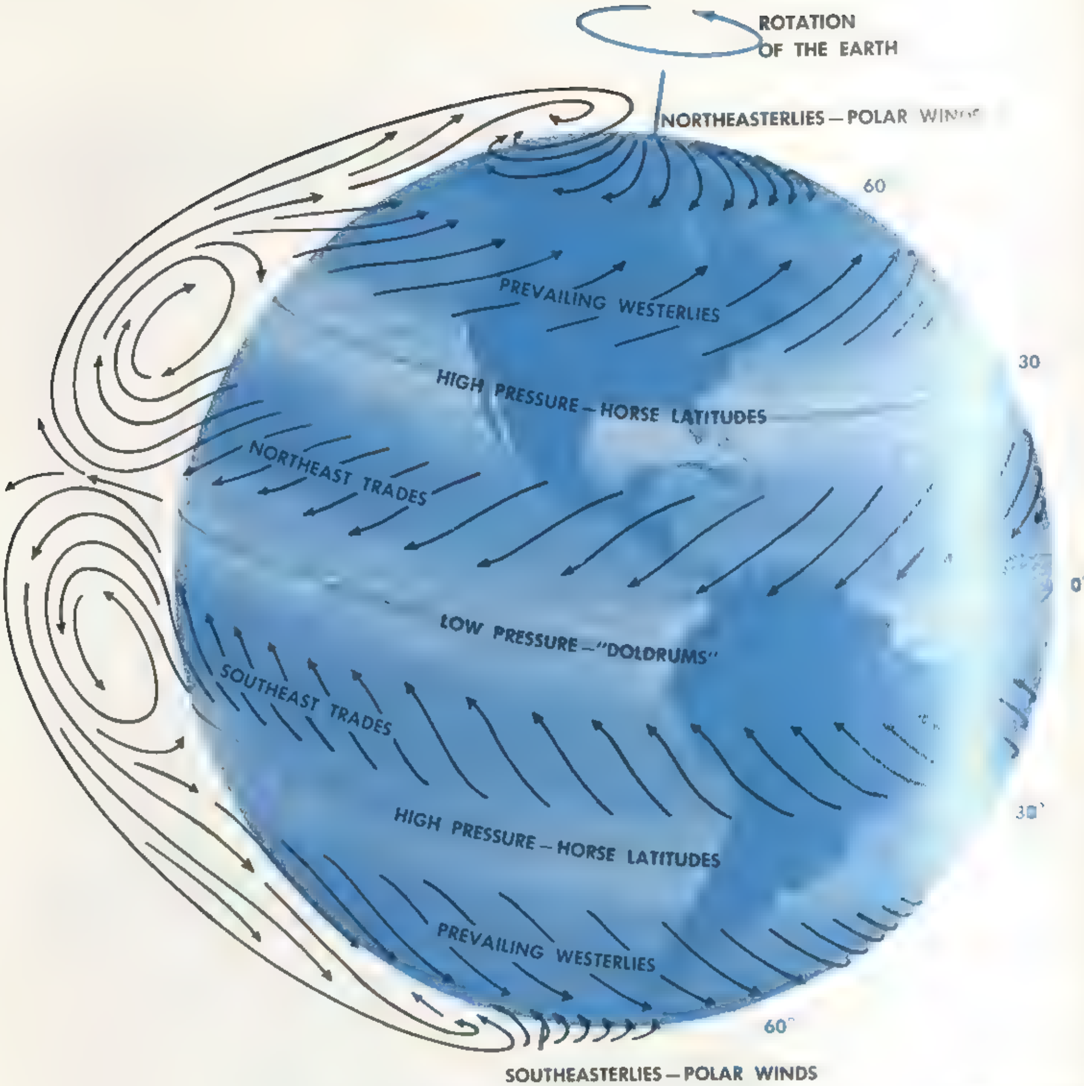
At the surface of the earth, the direction of winds is indicated by wind vanes and their speed by anemometers. By following the drift of pilot balloons as they rise in the atmosphere, observers can determine the direction and speed of winds at upper levels. Rawinsondes – pilot balloons carrying radar targets – can be tracked by radar even when they rise above the clouds and are invisible from the earth. The pressure of the air at the earth's surface is indicated by the instrument called the barometer. Pressure in the upper air is measured by a balloon-borne device called the radiosonde. It also measures temperature and humidity.

THE BEAUFORT SCALE

The Beaufort wind scale is often used to indicate wind velocity. This scale was introduced by Sir Francis Beaufort, an English admiral, in the first decade of the nineteenth century. He based it on the force with which the wind blew on the sails of a vessel. He divided winds into thirteen

THE BEAUFORT SCALE (for indicating wind velocity)

SCALE NUMBER	WIND VELOCITY KILOMETERS/ HOUR	DESCRIPTION OF WIND	INDICATIONS ON LAND
0	0-1.5	Calm	Smoke goes straight up
1	1.6-5	Light air	Smoke drifts
2	6-11	Slight breeze	Leaves rustle
3	12-19	Gentle breeze	Leaves and small twigs are in motion
4	20-29	Moderate breeze	Small branches move; dust and paper fly
5	30-39	Fresh breeze	Ripples on water; small trees sway
6	40-50	Strong breeze	Large branches move
7	51-61	High wind	The trunks of trees bend; walking is difficult
8	62-74	Gale	Twigs are broken off
9	75-87	Strong gale	Chimneys and shingles are carried away
10	88-101	Whole gale	Trees may be uprooted
11	102-120	Storm	Damage is widespread
12	Over 120	Hurricane	Any disaster may be expected



Large-scale movements of winds over the earth's surface. The wind belts named here are discussed in the article.

different classes on the basis of their speed and gave a code number—from 0 through 12—to each. Later this scale was applied to a definite range of wind speeds and it has been used widely ever since.

WIND BELTS

If we record our observations of the winds over a period of years, we find that there are certain definite large-scale wind belts. These are areas where the winds follow the same general direction for months at a time. These belts are the *doldrums*, the *trades* and *antitrades*, the *horse latitudes*, the *westerlies*, and the *polar winds*.

The doldrums. You will recall that at the equator the warm air is constantly ascending. This causes an equatorial belt of low pressure, in which calms alternate with variable winds. The name "doldrums" is given to this low-pressure belt. The word is probably derived from the English word "dull," and it means "a state of listlessness or boredom." As applied to the equatorial wind belt, the name goes back to the days of sailing ships, when it was most important to have favoring winds. Ships' captains were "in the doldrums" in this wind belt, where ships might lie becalmed for weeks.

The trades and antitrades. To the

north of the doldrums in the Northern Hemisphere and to the south in the Southern Hemisphere we find the trade winds. They represent the surface flow of air from the poles to the equator—a flow which the rotation of the earth deflects to the right in the Northern Hemisphere and to the left in the Southern.

A wind gets its name from the direction from which it is blowing. In the Northern Hemisphere, the trade winds blow from the northeast to the southwest and therefore are called the *northeast trades*. In the Southern Hemisphere, the trade winds blow from the southeast to the northwest and therefore are called the *southeast trades*.

The trades are generally steadier in direction that any other winds. The word "trade" in this case has nothing to do with business or commerce, but is used in the older meaning of "path" or "course." Trade winds are so called because they keep to a pretty straight course. Yet even these winds are not absolutely reliable. They sometimes shift their direction temporarily. They blow more regularly over the oceans, especially the Atlantic, than over the land.

Since the prefix "anti" means opposite, you might gather that the *antitrades* blow in the opposite direction from the trades—and that is exactly what happens. The antitrades are winds in higher levels of the atmosphere above the trade winds. They represent the outflow aloft from the equator toward the poles—an outflow that is turned in a general direction toward the east. The antitrades blow from the southwest in the Northern Hemisphere and from the northwest in the Southern Hemisphere.

The horse latitudes. Beyond the trades we find a belt where, as in the doldrums, calms alternate with baffling winds—the horse latitudes, or subtropical high-pressure belts. They are centered about latitudes 30° north and 30° south. Since the air is descending in this high-pressure area, surface winds are often absent. When the wind blows, it is irregular and weak. Various explanations of the name "horse latitudes" have been offered. According to one explanation, vessels carrying horses from Europe to the West Indies in colonial days were sometimes becalmed so long that the horses's feed and water gave out, and the animals had to be thrown overboard. Another theory has it that the horses succumbed because they could not stand the unfavorable conditions in this wind belt.

The westerlies. Still farther removed from the equator we find the winds known as the prevailing westerlies. In this belt the winds tend to blow poleward but are turned by the earth's rotation. In the Northern Hemisphere they become southwest or west winds, and in the Southern Hemisphere, northwest or west winds. They are particularly strong over the ocean. Since there is more ocean area in the Southern Hemisphere than in the Northern, prevailing westerlies in that area are so boisterous that the region over which they blow (between latitudes 40° south and 50° south) is known as the *"roaring forties."*

The polar winds. The belts of the polar winds tend to blow from the usually cold areas at the poles toward the equator, but they are turned by the earth's rotation. They become northeast winds in the Northern Hemisphere and southeast winds in the Southern. They are sometimes called northeasterlies and southeasterlies, respectively.

There are important changes in the wind belts in the course of the year. These changes are due to alternation of the seasons and the resulting differences in the rates of heating and cooling of landmasses and ocean areas.

JET STREAMS

Meteorologists have discovered that swift westerly winds flow in a band several hundred kilometers wide at heights of from 6,000 meters to 12,000 meters above the earth's surface. These currents are aptly called *jet streams*, or *jets*. They are really swift jets of air that move faster than the air on either side or above them or below them. The average speed of the air in the core, or central part, is 160 kilometers or so in the winter and 80 kilometers in the summer, but speeds of over 400 kilometers per hour have been observed. The speed of the currents making up a jet stream decreases

outward from the core. The number and paths of the jets vary from week to week and sometimes from day to day. The strongest jets, in the Northern Hemisphere, flow across Japan and the United States.

Jet streams tend to move over certain areas at certain times. In winter, for example, they are frequently discovered over the region extending along the coast of the Gulf of Mexico up through the Carolinas. In the summer, they are seldom found over that region but are common over and north of the Great Lakes. Thus they migrate with the seasons—northward in summer, southward in winter.

The jet streams play an important part in weather changes. For example, jets moving northward tend to pull masses of warm air with them. As they flow south, they pull the cold air from the arctic regions into the temperate zones. Meteorologists plot the course of the jet streams, and thus obtain information about prospective movements of invading air masses.

Flying schedules for high-flying planes must take account of jet streams. Pilots of eastward-bound planes deliberately fly into jets in order to take advantage of the favorable winds, which will add greatly to their flying speeds. Westward-bound pilots, however, dodge the jets in order to avoid the head winds they would encounter in these swift currents of air.

LOCAL AND REGIONAL WINDS

The prevailing winds blow over huge areas of the earth's surface. There are also many local winds, which blow fairly steadily for considerable periods of time over comparatively small local areas.

The circulation of air over mountain ranges is responsible for many local winds. The wind crossing the northern side of the Alps from the south in the winter and early spring is called the *foehn*. It loses most of its water vapor as it ascends the mountain slope. As this vapor is condensed, it may give rain or snow. When the foehn descends the opposite side of the slope, it has become warmer and very dry. The name foehn is applied to similar winds in other areas. The foehn of the Rocky Mountain area is called the *chinook*. It blows from west to east, warming and drying the prairies that lie east of the Rockies.

In the Adriatic region, we find the dreaded *bora*, which makes itself felt particularly along the shores of Dalmatia. The bora is a cold northwesterly wind. It is caused by the cold and dense air of the mountains making its way to the sea, where the air is warmer and less dense.

The wind known as the *mistral* prevails more than a hundred days a year in the lower Rhone Valley. When this wind blows, the skies are generally cloudless, the

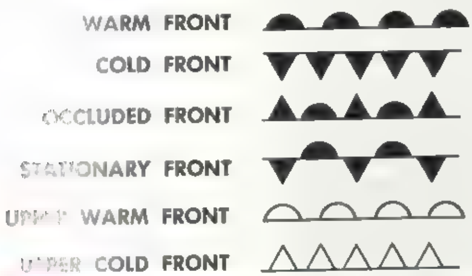
Jet streams are rapid westerly winds flowing in bands several hundred kilometers wide. Eastward-bound planes fly deliberately into jet streams to take advantage of the favorable winds. Westward-bound planes dodge the jet streams to avoid head winds they would meet in these rivers of air.

atmosphere is dry, and the cold is biting. Sometimes the mistral is very violent.

The winds blowing from the Sahara have been given different local names. Among the most noted of these winds is the hot and dust-laden *simoom,* or *simoon.* It blows in Saudi Arabia and Syria and other lands of the eastern Mediterranean area. Another wind from the Sahara is the *harmattan,* which makes itself felt along the Atlantic coast of Africa. The *sirocco,* a hot wind from the Libyan deserts, blows over Malta, Sicily, and Italy.

AIR MASSES AND FRONTS

The prevailing and local winds that we have just described follow roughly a course that will not vary greatly. But other systems of air circulation are quite erratic. These are movements of cold and warm air masses, which form over different areas of the earth's surface and which travel great distances.



Left: the symbols for the different fronts as presented in weather maps. Below: how the fronts appear in a typical weather map prepared by the U.S. National Weather Service.

U.S. National Weather Service

Australian Information Service

Bill Garlow, Journal Herald, Dayton, Ohio

When contrasting air masses meet, a violent traveling wind system often results and brings with it death and destruction. Upper left: city of Xenia, Ohio, half-destroyed by a tornado, a local violent wind system. Lower left: the city of Darwin, Australia, destroyed by cyclone Tracy in late 1974.

The air masses in question differ according to the source regions—that is, the areas over which they form. The circulation of the atmosphere may cause air to linger over the tropical oceans. As a result, the air mass becomes warm and moist, and is called *tropical maritime*. An air mass that originates over land in the tropics is known as *tropical continental*. *Polar continental* air masses form over polar land regions. *Polar maritime* masses form over the polar oceans. All these masses retain their characteristics for a long time after moving away from their source regions.

The boundaries between air masses are known as *fronts*. The boundary of relatively cold air of polar origin, advancing into an area occupied by warmer air, usually of tropical origin, is called a *cold front*. When relatively warm air advances into an area occupied by colder air, it causes a *warm front* to form. When a cold front over-

takes a warm front and displaces it completely at the earth's surface, forcing it upward, the two fronts are combined to form an *occluded front*. Sometimes two air masses remain in contact for some time without encroaching upon one another. The boundary between two such masses is called a *stationary front*.

CYCLONES AND ANTICYCLONES

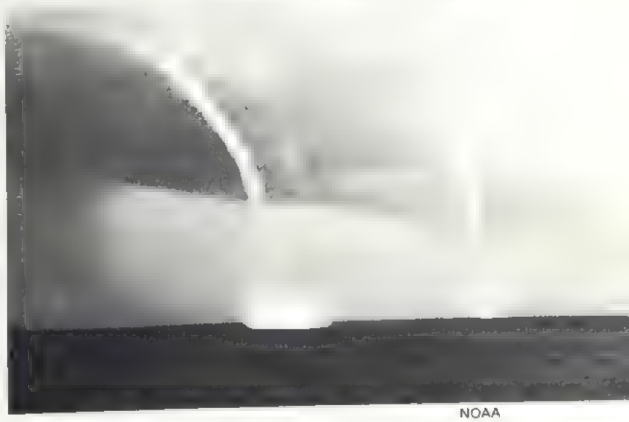
When two contrasting air masses meet, the air currents flowing along their front generally move in opposite directions. The rotation of the earth will cause these currents to curve. They are then apt to form a gigantic vortex, or whirl, with the winds spiraling toward a low-pressure area at the center. The resulting wind system is known as a *cyclone*. Some cyclones move, roughly at least, in a circle. Other cyclones describe an ellipse; still others form irregular patterns. The winds of a cyclone system turn counterclockwise in the Northern Hemisphere and clockwise in the Southern.

Sometimes the winds flowing outward from a high-pressure area in the center of an air mass are curved by the rotation of the earth so as to form a rotating wind system known as an *anticyclone*. These winds spin in the opposite direction from those that make up a cyclone. They turn clockwise in the Northern Hemisphere and counterclockwise in the Southern.

In 1857, the Dutch meteorologist Christoph H. D. Buys Ballot gave a rule for determining air pressure, as applied to cyclonic and anticyclonic circulation. Here is the rule, stated in his own words: "Stand with your back to the wind and in the Northern Hemisphere pressure will be lower on your left hand than on your right, while in the Southern Hemisphere the reverse will be true."

Both cyclones and anticyclones are traveling wind systems. They may be compared to spinning tops. They have a rotary motion as they move from place to place. Cyclones are sometimes called *lows* because their winds move toward a low-pressure area at the center. Anticyclones are sometimes called *highs* because their winds move out from a high-pressure center.

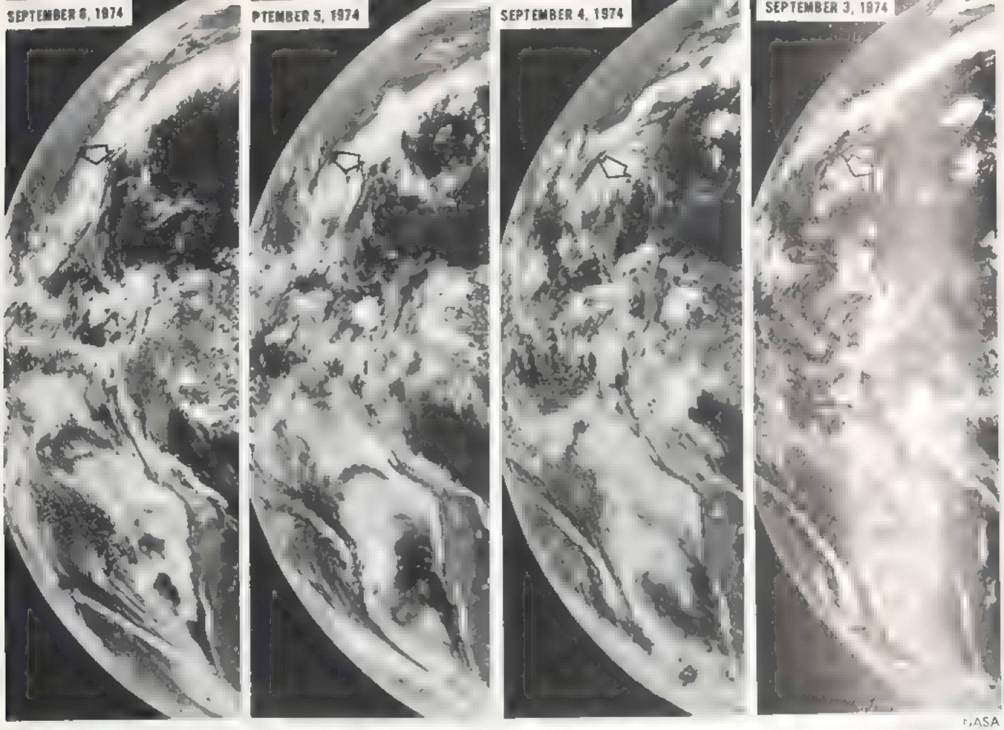
UPI



NOAA

In a tornado a funnel-shaped cloud with violent winds makes its way to the earth. Top photo: the narrow end of the funnel sweeps along, at or near the ground, leaving a path of destruction. Lower photo: a waterspout, or tornado at sea. The funnel sucks up water, forming a spray.

In the normal course of events, when a cyclone moves out of a given area in the middle latitudes, it is followed by an anticyclone. The anticylone in turn is followed by a cyclone. In the United States, this cycle may be completed in four or five days. The shifts between cyclones and anticyclones bring about various changes in the weather. Cloudiness and rain or snow will be fol-



A weather satellite provided this series of photos showing the develo[illegible] and movement of a hurricane northward across the Gulf of Mexico, near [illegible]

lowed by clearing skies and colder weather.

HURRICANES AND TYPHOONS

The most violent winds are all of the cyclone type. Among these are the *hurricanes*, or tropical cyclones, so called because they arise in tropical or subtropical regions. They are particularly frequent in the Caribbean Sea, the Gulf of Mexico in the western Atlantic, off the east and west coasts of India, east of southern Africa, and north of Australia. The tropical cyclones of the western Pacific are known as *typhoons*. Those of India are called cyclones.

We have already compared a cyclone to a top, spinning rapidly as it advances slowly. The destructive effect of hurricanes is due chiefly to this spinning motion, which may reach a speed of more than 160 kilometers per hour. The forward movement of the hurricane in low latitudes is comparatively slow—usually from 15 to 25 kilometers per hour.

Sometimes a hurricane causes great damage. Trees may be uprooted and frame houses crushed like matchwood. People who happen to be out of doors during such a storm run great danger of being battered to the ground or of being struck by flying fragments of all kinds. Along the coast, hurricanes often pile up the surface waters and cause disastrous waves. These waves can submerge the land sometimes to a depth of 15 meters or more. Hurricanes can severely batter the stoutest ocean liners and overwhelm smaller ships.

Despite the destructive force of the outer area of the hurricane, the wind is calm at its *eye*, or center. That is why a hurricane may seem to strike a double blow in some places. First, there are the raging winds in the van of the hurricane. Then there is the relative calm of the eye. Finally, after the eye passes, there is the violence of the winds that make up the rear guard of the hurricane.

Fortunately, much progress has been made in giving timely warning of a hurricane's approach. Particularly effective warning is provided by hurricane reconnaissance aircraft, equipped with radar and many meteorological instruments. These planes search for hurricanes in suspected areas. When the characteristic whirling cloud formation has been spotted on the radar screen of one of the planes, the craft

will fly right into the hurricane. Thus it will be able to obtain exact information about the nature of the hurricane, its course, and the speed with which it is advancing. This information will then be radioed to ground stations. An important advance in the spotting of hurricanes has been contributed by weather satellites. These satellites, orbiting far above the surface of the earth, transmit to earth television pictures of cloud formations over wide areas. They can photograph the development of a hurricane and follow its path, providing warning of the storm's approach even when it is still in its early stages.

TORNADOES

The cyclones that occur outside of the tropics—the extratropical (out-of-tropics) cyclones—are usually rather mild wind systems. There are exceptions, however. Sometimes a cyclone, in combination with an anticyclone, develops great force. It may cause a cold wave or a blizzard, a gale with heavy rain or heavy snow, or a local storm.

The local type of cyclone known as a *tornado*, or twister, is particularly destructive. Like all cyclones, it arises along the front of opposing air masses. There are very strong air currents flowing in opposite directions along the front at lower cloud levels. If an updraft of warm air is carried aloft at some place along this wind front, a whirl is formed, drawing its force from the opposite winds and spinning around the low-pressure area represented by the updraft.

As the winds revolve around the low-pressure center, they may reach speeds of from 300 to 500 kilometers an hour. Finally a spinning, funnel-shaped cloud makes its way to the earth. As the narrow end of the funnel sweeps along the ground, it strews destruction in its wake. Sometimes the funnel narrows so that it assumes the appearance of a dangling rope. At other times it passes by at a height of 15 meters of more above the ground, sparing the objects under it.

The path of destruction is very narrow, compared to that of a hurricane. It ranges from 5 to 900 meters and it averages a few hundred meters. Yet within its path a tornado is even more destructive than a hurricane. The raging winds flatten houses and strip the ground of its vegetation. Cyclones have been known to drive stones through brick walls. Tonadoes are most frequent in the United States. They occur particularly in the southern and western areas.

A tornado at sea is called a *waterspout*. As its funnel reaches the surface of the ocean, the water is sucked up, forming a whirling spray fountain which may reach a height of 15 meters or more. Waterspouts are far less destructive than tornadoes for the simple reason that there is less to destroy at sea than on land. Since they can be seen from great distances and travel slowly, it is comparatively easy to avoid them, in daylight at least.

MAJOR CHANGES IN CIRCULATION

In addition to all the variations in the circulation of the air that we have considered, certain large-scale changes make themselves felt from year to year and from decade to decade. For example, for several years in succession there is more air in the Northern Hemisphere than in the Southern. Following this period there is a greater-than-average accumulation of air in the Southern Hemisphere. We do not completely understand these changes. They seem to be related to small but widespread temperature differences over the vast ocean surfaces.

Long-term changes in the circulation of the atmosphere seem to be associated with periods of warm and dry years alternating with periods of cold and wet years. Successful weather forecasts for months and seasons are not likely until the meteorologist learns more about these cycles.

In the past generation or two, meteorologists have been steadily filling in the gaps in our knowledge of the wind belts of the earth and the day-to-day, seasonal, and long-term changes that are so important to mankind. Yet more data must be made available, particularly about conditions in the upper atmosphere, before we can consider ourselves well informed about the different phases of the subject.

LIGHTNING AND THUNDER

by James Stokley

A brilliant flash of lightning, followed by the deafening roll of thunder, is one of nature's most awe-inspiring displays. It is small wonder that in ancient times people attributed lightning to supernatural causes. The early Greeks, for example, believed that the mighty god Hephaestus forged thunderbolts in his smithy. The father of the gods, Zeus, hurled these thunderbolts at his foes.

Today, though we may still hold lightning in awe, we know that there is nothing supernatural about it. It is simply a rapid succession of huge electric sparks. It is the same sort of thing as the little spark that passes from your finger to a doorknob, say, after you have rubbed your feet on a rug on a cold winter day. The crackle you hear as the spark jumps from your finger corresponds to thunder.

CHARGES AND SPARKS

To understand what lightning and thunder are, we must recall what we know about the atom. The typical structure of an atom has a nucleus, or center, containing positively charged particles—protons—and neutral, or uncharged, particles—neutrons. Negatively charged particles known as electrons revolve around the nucleus. The number of electrons ranges from one to over a hundred, depending on the atom.

Ordinarily, there are as many protons as there are electrons in an atom. Their charges cancel each other out. Thus there is no net, or overall, electric charge. We say the atom is neutral. But when an atom either gains or loses electrons, a charge is acquired. The atom is negative when electrons are gained; it is positive when electrons are lost.

When a negatively charged object touches one that has a positive charge, electrons flow from one to the other so that the objects become neutralized. In fact, if the charges are great enough, we do not need to bring the objects into contact, for electrons will jump across the space separating them, making a spark. A lightning flash is just such a spark on a vast scale. We cannot see the electrons themselves. What we do see is air that has been made to glow by the passage of these charged particles.

ANALYSIS OF LIGHTNING FLASHES

A great deal of what we know about lightning flashes is due to the work of a South African scientist, Sir Basil Schonland. He took many photographs of lightning, using a special camera with fast-moving film. With this camera he recorded different stages of a single flash separately.

Lightning is associated with thunderclouds. As a typical thundercloud begins to form, a mass of warm air moves upward. This mass carries along a considerable amount of moisture, in the form of water vapor. As the mass rises, it gets cooler. Now it can hold less water vapor than it could when it was warmer. The excess vapor condenses into tiny droplets of water that form clouds.

Water usually freezes at 0° Celsius. Under certain conditions, however, it will remain a liquid at much lower temperatures, even as low as −40° Celsius. In this state the water is said to be *supercooled*. The water droplets that form in thunderclouds become supercooled. They rise much higher than the level in the atmosphere at which the temperature is 0° Celsius. Finally they reach a level so high that the temperature is down to −40° Celsius. The water droplets then turn into tiny lumps of ice.

Hailstones and splinters. Some of the frozen droplets join others by freezing together. Thus they form small hailstones.

These begin falling because of their weight, but they continually bump into supercooled droplets moving upward. The water in each droplet freezes onto the hailstone it encounters, and the hailstone gradually increases in size. At each encounter with a droplet, the hailstone acquires a negative charge. Sir Basil was convinced that millions of such encounters between water droplets and hailstones produce in the cloud the electric charge that finally brings about the flash of lightning.

At the same time, a very small splinter of ice cracks off from the water droplet as it freezes. The splinter carries a positive charge. Rising air currents carry these splinters and their positive charges to higher parts of the cloud.

As the positively charged splinters rise in the cloud, the negatively charged hailstones fall toward the bottom, where it is warmer. And so the hailstones melt into large drops of water. This process may continue for an hour. During this time, according to Sir Basil, the whole cloud is a huge generator, continuously producing nearly a million kilowatts of electricity. It acts, too, like a great storage battery, with the positive terminal at the top and the negative terminal perhaps several kilometers below. Between the two terminals, there may be a voltage difference of 100 million volts.

Trigger discharge. While the main charging process has been taking place, a smaller pocket of positive charge has built up at the base of the cloud, below the negative pole. It is here that the triggering action that sets off the lightning flash occurs.

A trigger discharge jumps from this pocket of positive electricity to the negative pole, a short distance above. Now all of the lower positive charge, as well as some of the negative charge, is neutralized. Moreover, the path through which the discharge occurred remains conductive. Through it now passes the remainder of the negative charge. The traveling negative charge continues downward, attracted by a positive charge on the ground.

NOAA

Lightning is well called "nature's fireworks." Here it makes quite a spectacular display, jumping in all directions.

The discharge does not jump in one huge spark. Instead, it feels its way, guided by local variations in the electric field ahead of it. It may form branches, part going one way, part another.

Pilot discharge. First, a rather faint "pilot" discharge, about 5 meters in diameter, travels downward at some 140 kilometers per second. After it has gone approximately 30 meters, it suddenly gets much brighter. It now becomes the surge of electrons known as a *leader*. The leader moves down in steps until, after about 1/100 of a second, it is close to the ground.

By this time, there is a difference of some 10 million volts between the tip of the leader and the ground. As a result, a positive charge builds up on a projecting tree or building. This discharges *streamers* that extend upward to meet the leader and guide it to the tree or building. When leader and streamers are about 30 meters apart, they unite in a short circuit.

Now, according to Sir Basil, a very brilliant return streamer moves up along the path of the stroke, at about 100,000 kilometers per second – 1/3 the speed of light. Current – perhaps as much as 100,000 amperes – continues to flow between the cloud and the ground. It stops when all of the charge in the region of the cloud that was first triggered has passed to the ground.

Dart leader. After about 1/25 of a second, the process may be repeated, this time from a higher region in the cloud where there is still some electric charge. Again, there is trigger action, and a leader. But this is a "dart" leader. It does not move down in steps, but steadily, along the path of the first stroke. Again the same process occurs at the ground, and again the return streamer moves up to the cloud.

Several more strokes may occur, each from a still higher place in the cloud. Finally the discharge action reaches the region where the temperature is −40° Celsius and all the water is frozen. Temporarily, at least, the action halts, because there are no more supercooled water droplets to build up the charge. But once again, hailstones may begin falling and growing as they encounter rising droplets, thus building up the charge for another stroke.

Most meteorologists favor the ice-and-water-droplet explanation of how a thundercloud becomes charged. Some do not, however. They maintain that ice particles are not necessary to charge a cloud. Research is continuing on how, exactly, electricity forms in clouds.

Flashes may be from one cloud to another, or within the same cloud. Conducting objects that extend upward, like trees, buildings, or masts of ships, are nearer to the cloud than the surface of the earth is. There is a concentration of positive charges at the tops of these objects. This concentration may be enough to cause the brushlike discharge of electricity that is called *St. Elmo's fire*.

THUNDER

As lightning strikes, the energy that is liberated heats the air through which it passes, and the air suddenly expands. This results in a pressure wave that travels outward and gives a sensation of sound to anyone close enough to hear. The long-drawn-out roll of thunder from a single stroke may last many seconds, for several reasons. Sound travels in air about 330 meters per second, or about a kilometer in three seconds. Therefore, if a stroke from a cloud a kilometer up hits near you, the first sound comes from the end of the stroke, perhaps less than 100 meters away. Then gradually the sound waves that started from the higher parts of the flash reach your ears. At the end, 3 seconds after the first sound, those from the top of the stroke arrive.

Since the usual stroke takes an irregular path, there may be sudden changes in the nature of the sound waves. This brings about the rolling and rumbling effects of thunder. Reflections, or echoes, from hills or buildings may cause these sound effects to continue even longer.

Our knowledge of the speed of sound gives us a simple method of determining the approximate distance of a lightning flash. When you see the flash, start counting seconds. A rough-and-ready way of doing so without consulting a watch is to say: "One hundred and one, one hundred and two, one

hundred and three," and so on. If you speak at a normal rate, it will take you something like a second to say each one of these numbers. Stop when you hear the first peal of thunder and divide the number of seconds by three. You will then have the distance in kilometers to the nearest part of the stroke.

Sometimes, on summer evenings, we see so-called *heat lightning*—silent flashes of light over a large part of the sky. This is merely the light produced by very distant storms. These disturbances are so far away that we cannot see the individual strokes or hear the accompanying thunder.

There are certain lightning strokes that produce no thunder. In these, the current builds up to only a very low value—perhaps no more than 100 amperes. As a result, the pressure is too low to produce the sound waves that constitute thunder.

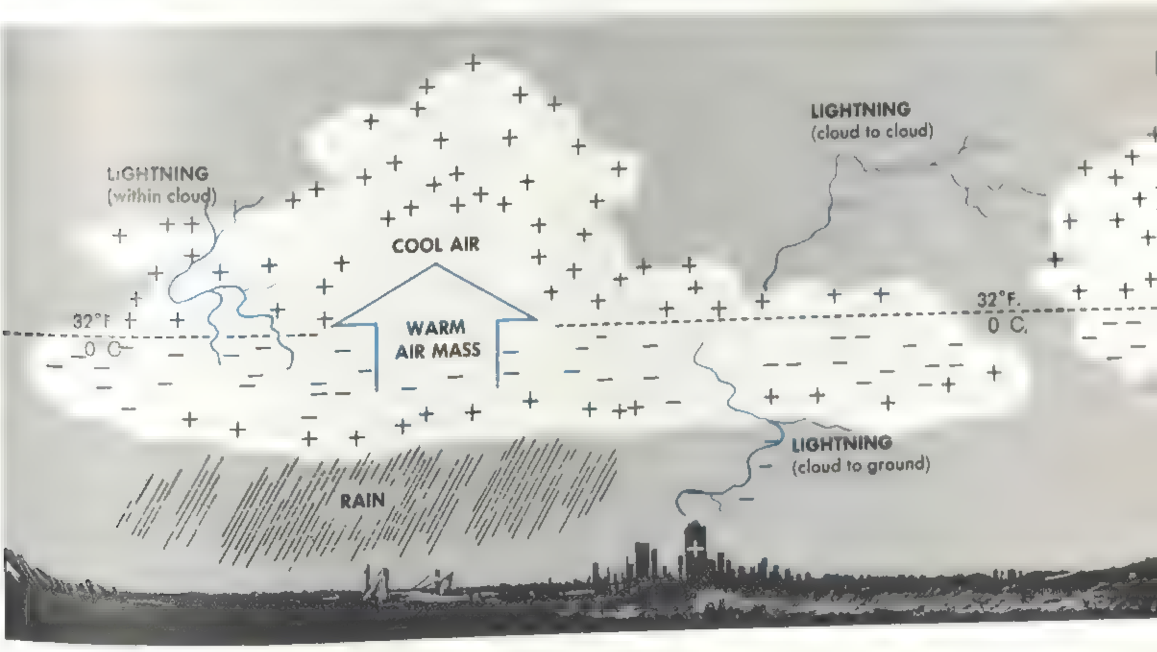
STUDY OF LIGHTNING

The first distinguished investigator of lightning was Benjamin Franklin, the justly honored American scientist and patriot. He had come to the conclusion that the spark produced by "electrical fluid" was like lightning in many ways. To put his theory to the test, he carried out, in the year 1752, one of the most famous experiments in the history of science.

To see if he could draw "down the Lightning to a sharp point," Franklin made a silk-covered kite and attached a wire to the top of it. A long linen string led from the kite, and a silk ribbon was tied to the end of the string. He then fastened a key to the string at the place where it was attached to the silk ribbon. Franklin proposed to fly the kite during a thunderstorm. He expected that, when lightning struck in the vicinity, an electric charge would be carried along the string, since wet linen thread is a fairly good conductor. But the experimenter would be protected from the charge, since he would be holding the dry silk ribbon, and dry silk is an insulator.

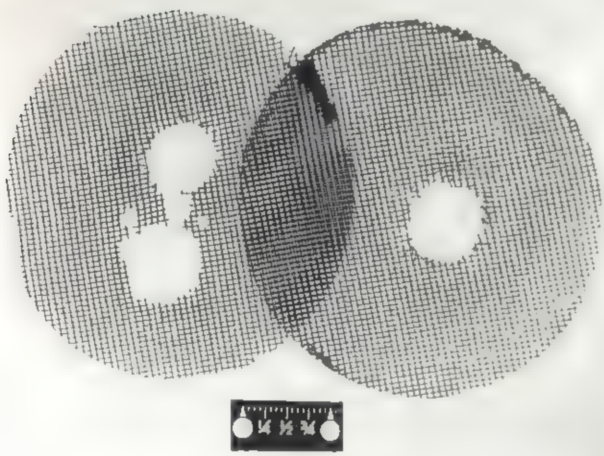
The kite was raised during a thunderstorm. Franklin was able to draw sparks from the key by bringing his knuckle near it. He also performed experiments that he had formerly carried out with electrical apparatus. He came to the conclusion that lightning was a gigantic electric spark.

The distribution of electric charges within a cloud accounts for lightning. Lightning flashes jump from negative to positive regions.



Westinghouse Electric Corporation

Klydonograph. This instrument can be used to create an image of power surges from a bolt of lightning and to measure the voltage of the lightning.



Westinghouse Electric Corporation

These metal grids were struck by lightning. The diameter of the bolt of lightning can be determined simply by measuring the diameter of the hole produced in the metal grids.

Franklin ran considerable risk during this landmark experiment. Happily for the course of American history, however, he took the precaution of standing under the roof of a shed where neither he nor the silk ribbon he was holding became wet. Wet silk is a conductor of electricity and a human body conducts electricity much better when it is wet. Several [illegible]gators who attempted the kite exper[illegible] were struck by lightning because they [illegible]ot take this simple precaution.

Steinmetz generator Among the famous investigators of lightning in the twentieth century was Charles Proteus Steinmetz, a German engineer, who went to Schenectady, New York [illegible]93, to join the General Electric Co[illegible] In the early 1920s he began to make artificial lightning generators, in order to study the effect of lightning. He used an electrical condenser to store up a huge electric charge, as in the cloud. When it reached its peak value, the electricity discharged in an enormous spark–the flash of man-made lightning. It was then possible to observe the effects of the lightning striking models of, say, buildings.

After Steinmetz's de[illegible] 1923, larger and more powerful [illegible]ators were built. They enabled scient[illegible] to discover more valuable facts about lightning and about the precautions to be taken against it.

Lightning rod studies. In 1935, engineers set up apparatus in the Empire State Building in New York City [illegible] order to find out what happened when lightning struck this structure, which at that time was about 380 meters high. The lightning hit a special rod at the top of the building. This rod was connected to the steel frame of the structure, so that strokes that hit it were harmlessly carried to earth. A very small portion of the current that flowed from the rod was diverted through instruments that recorded the shape and other characteristics of the stroke. At the same time, photographs of the flashes were taken from another building.

These experiments proved that there is no basis for the belief that lightning never strikes twice in the same place. The Empire

Westinghouse Electric Corporation

Artist's conception of ball lightning. Ball lightning is a grapefruit-sized sphere of light that hovers close to the ground during thunderstorms. Scientists can only speculate about the reasons behind

State tower has been struck by lightning as many as 42 times in one year. It was hit 12 times in a single storm, and on one memorable occasion, 9 times in 20 minutes. And yet there was no damage to the building.

EFFECTS OF LIGHTNING

Lightning is, however, often dangerous. It kills some 400 people in the United States annually, most of these victims being struck in open, exposed locations. It injures an additional 1,000 people. They suffer from electric shock and, often, burns. We shall see, however, that one can take effective protective measures against lightning.

Lightning may be considered beneficial to man in one respect. It helps to provide food for growing plants. Plants require nitrogen. This element is absorbed through the roots, not in pure form but in nitrogen-containing compounds called nitrates. There is plenty of nitrogen in the air, but it is useless to plants unless it can be made to combine with other elements to produce nitrates—a difficult task. Every flash of lightning causes a certain amount of nitrogen in the air to unite with oxygen. After several further steps, the nitrogen is made available to the plant in the form of nitrates that it can absorb. Actually, lightning accounts for only a comparatively small part of the nitrogen used by plants.

Lightning is a cause of forest fires, which, of course, may be devastatingly destructive. It also causes a great deal of damage as a result of heating and expansion. When it passes through wood, for example, the enormous current heats the wood and causes it to expand many times. As a result, the wood may split. In addition, moisture in the wood is converted into vapor, and this adds to the general effect of expansion.

When lightning strikes, it may follow a very complicated path. A stroke of lightning once hit a large elm in front of a country house. From the tree, it jumped to the house, just below the eaves, and went through the wall to an iron bed where a man was sleeping. By great good luck, he was unharmed. Next the stroke passed into the floor and jumped to the stove in the kitchen, just below. From the stovepipe, it went across the kitchen to a wire connected with the telephone. Finally, it went into the ground.

If a lightning stroke with a low continuing current strikes sandy ground, it generally melts the sand. Later, the sand hardens in the form of a hard tubular mass called a *fulgurite*—a permanent record of the course of the discharge. Short discharges with high currents do not produce fulgurites. In these cases, the sand is just blown away.

SAFEGUARDS

The principal protection against lightning is the lightning rod, which was invented by Benjamin Franklin. It consists of a metal rod extending up from the roof or some other high point of the building. It is connected by a heavy wire to a metal plate buried in the ground. Franklin thought that the lightning rod was effective because it let current leak away harmlessly from the ground into the air. This explanation is incorrect. What the lightning rod does is to provide an easy route for the lightning, so that it will not take a destructive path if it strikes a house. A lightning rod affords protection in a cone-shaped area around it. The apex, or top part, of the cone corresponds to the tip of the rod. The base has a diameter two to four times the height.

To protect electric-power transmission lines from lightning, another arrangement is used. Above the current-carrying wires, borne on large steel towers, another wire is run, grounded at frequent intervals through the towers themselves. A lightning stroke will hit the protective wire and will be carried safely to earth. The transmission wires beneath it will not be affected.

A steel-frame building is safe in an electrical storm. This is because a lightning stroke will pass through the framework into the ground and will not hit the people in the building. Furthermore, if the structure is very high, it will provide a protective cone for some of the smaller buildings nearby. A building that is entirely within such a protective cone will be safe in a thunderstorm. Any part of the building extending beyond the cone may be struck by lightning.

A person who is caught out of doors in a thunderstorm may decide to seek shelter under a lone tree. This is as dangerous a place as he could select. The tree is much more likely to be struck than the ground in its vicinity is, since it affords a much readier path for the lightning stroke. It may carry some of the discharge into the ground, but it is not usually a good enough conductor to carry much current. A person who takes shelter under a tree may be struck by a side flash of lightning, or he may be hurt by flying branches. It is safer to lie down on low ground than to remain on high ground. Also, a forest—as opposed to a lone tree—is safer than an open area.

It is particularly dangerous to swim outdoors during a thunderstorm, or even to be in a rowboat or canoe. If lightning strikes the water, as it often does, enough current may be carried for a considerable distance to injure a person. If he is swimming, he may be stunned and drowned, even if the stroke is not fatal in itself.

It is risky to take a bath or a shower during an electrical storm, because a stroke hitting some other part of the building might be carried through the plumbing and pass through the person's body. For the same reason, one should not sit on or near a radiator.

One should not use electrical equipment any more than necessary during a storm, for the wires might carry the current of a stroke to the person near such equipment. This does not mean that one should sit in the dark, for it does not matter whether the lights are on or off.

It might be dangerous to stand in front of a fireplace. A person might be injured by the lightning stroke if its path led down the chimney. If the chimney were hit, all near the fireplace might be struck by debris.

You should take sensible precautions in a thunderstorm, but you should never give way to panic. After all, the chances of your being hit by lightning are slim. It might be well, also to recall this passage from *Playing with Lightning*, written by the American investigator of lightning Karl B. McEachron:

"If you heard the thunder, the lightning did not strike you. If you saw the lightning, it missed you; and if it did strike you, you would not have known it."

© 1976 W. Curtsing/Photo Researchers

CLOUDS AND FOGS

The clouds that hover serenely or scud rapidly in the atmosphere represent a gas—water vapor—that has condensed, or turned into a liquid or a crystalline solid. Some of this vapor comes from the evaporation of water in seas, lakes, and streams and from the exhalations of man and animals. Some is derived from the transpiration of plants—that is, the giving off of water vapor that occurs in leaves and other exposed parts of vegetation. Vapor is also given off in considerable quantities during volcanic eruptions.

WATER VAPOR IN AIR

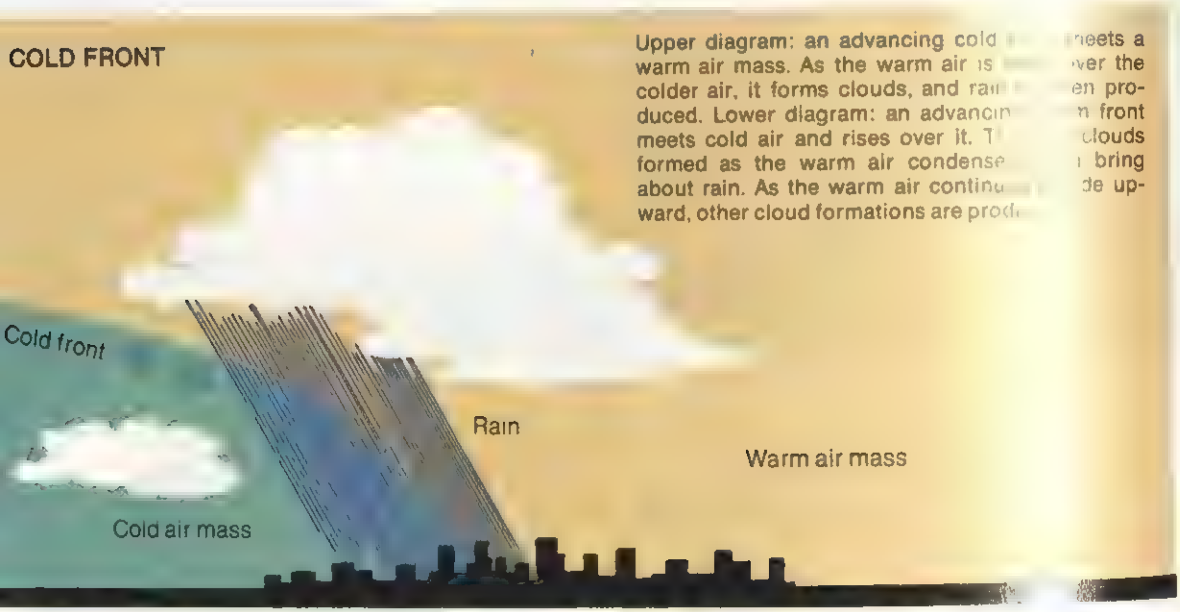
A given mass of air can hold only a certain quantity of water vapor. This amount will depend upon the temperature. The higher the temperature, the more vapor the atmosphere can hold. If the air is cooled at constant pressure without change in the vapor content, it will finally become saturated. The temperature at which this occurs is called the *dew point*. If further cooling takes place, a part of the vapor will condense on such airborne particles as dust and ocean salts derived from sea spray. The condensed water vapor, which is in the form of tiny droplets, becomes visible as fog, mist, or haze at low levels. If vapor condenses at heights of about one kilometer or more above sea level, it forms clouds. When the temperature is considerably below freezing, the water vapor may condense into liquid and then quickly freeze, or it may become directly converted into ice crystals.

The chief difference, then, between fogs and clouds is their place in the atmosphere—that is, the height they reach. Fog may arise on sea or land. Its density depends upon the number and the size of the water droplets in it. A particularly dense formation may contain from 600 to 1,200

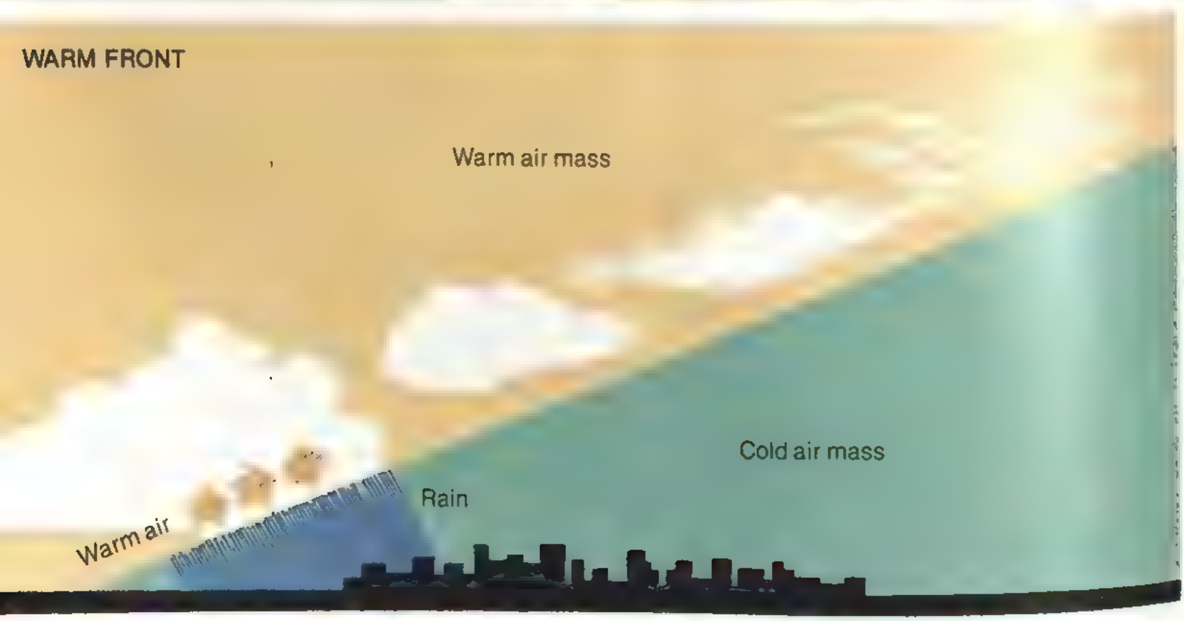
droplets per cubic centimeter. Even the densest fog, however, has an astonishingly low water content. The water contained in a fog that blankets a harbor area would scarcely fill half a dozen fair-sized buckets. The water in a light fog will be much lower. We call such a formation a *haze*. When particles are like tiny raindrops as they float or fall, the formation is known as a *mist*.

HOW CLOUDS ARE FORMED

How do the invisible particles of evaporated moisture rise to the levels where clouds, rather than fogs, are formed? Some of the particles are carried upward by convection—the vertical movement of air that, for example, is revealed by the smoke from a bonfire on a quiet autumn evening.



Upper diagram: an advancing cold [illegible] meets a warm air mass. As the warm air is [illegible] over the colder air, it forms clouds, and rain [illegible] en produced. Lower diagram: an advancing [illegible] front meets cold air and rises over it. T[illegible] clouds formed as the warm air condense[illegible] bring about rain. As the warm air continu[illegible] de upward, other cloud formations are prod[illegible]

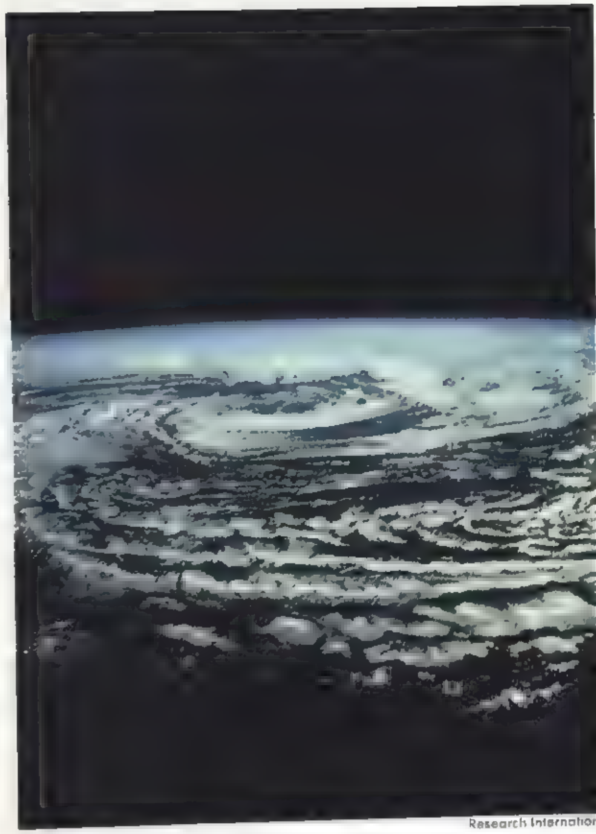


A mass of air will be forced up, much as a cork is forced up in water, if it is less dense than the air around it. Warm air is less dense than cold air; hence it will rise when it is surrounded by cold air.

Road and roof surfaces respond to the warming influence of the sun much more quickly than field, wood, and water surfaces, and they warm the air above them. Consequently, on a hot summer's day, the air temperature over a town soon rises above the temperature of the surrounding countryside. The mass of air above the city is warmer and therefore lighter than the air around it. Therefore, it floats upward. Its place is then taken by cooler air, which in turn warms up.

The rising mass of air keeps moving away from the warm town. It gradually gets cooler until it reaches the saturation point. When it goes beyond this stage, the water vapor begins to condense, and a cloud begins to form. As long as the temperature of the cloud is higher than that of the air around it, it will continue to ascend. When it has the same temperature as the air outside and is no lighter than that air, it will come to rest. The height the warm air will reach and the size of the cloud it will form with depend largely upon how fast the temperature of the atmosphere changes.

The rate of change in temperature above ground level is called the *lapse rate* of the air. While this lowering of the temperature is by no means steady, over thousands of meters it averages about 10° Celsius for every kilometer rise. This means that even in summer the temperature nine or ten kilometers above New York City, for instance, may be as low as −30° Celsius. This cooling rate, however, applies to the condition of the atmosphere only when it is at rest, or where there are no up-and-down currents in it. Suppose such currents are set in motion, as happens when warm dry air starts to rise. Provided the rising air does not give heat to its surroundings or receive heat from them, it will diminish in temperature at a steady rate of something like 10° Celsius for every kilometer rise. If the rising air contains considerable moisture, the latter begins to condense as the air temperature drops. As water vapor condenses, it gives off heat, which retards the cooling process of the rising air. The lapse rate is lower for moist than for dry air, which is about the same as the lapse rate for still air. After a time, the mass of air exhibits a visible cloud.



Research International

In a cyclone, clouds are caught in a gigantic vortex with violent winds spiraling toward a center.

Convection is only one of the ways in which invisible moisture is turned into visible clouds. There are other equally effective ways. For example, when a stream of damp air flows as a wind over the tops of a range of hills, the temperature at the hilltops may be low enough to cool the air below its dew point. Air that was comparatively dry at sea level may form clouds at these high altitudes. This explains why mountains, on the side from which winds are blowing, are so much cloudier and wetter than the valleys around them.

© 1961 W. Belknap Jr./Photo Researchers

Meteorologie nationale, Paris

Meteorologie nationale, Paris

Clouds of the high-cloud family—found above six kilometers—includes cirrus (top), cirrocumulus (middle), and cirro-stratus (bottom).

Clouds may be formed in this way even where there are no mountains. Cold, heavy air, like that which flows out from the Arctic periodically, makes an excellent "mountain" for this purpose. Any warmer, lighter air mass that happens to meet this cold air over a broad front will ride over it. It will become cooler and in time it will condense. This is what usually happens in winter when the warm air that flows up into the northern United States or Canada from the Gulf of Mexico meets the cold air moving southward from the polar regions. The warm and cold air masses behave like oil and water. Instead of mixing, the lighter mass flows over the heavier. Clouds originating in this way are called *frontal.*

Another common way in which clouds can form is by the passage of damp air over a colder surface, either land or water. This horizontal atmospheric movement is known as *advection,* to distinguish it from the vertical movement known as *convection.* If the air is moving slowly, this process will be more apt to produce fog than cloud.

CLOUD PATTERNS

The total pattern formed by clouds in a single area at a given time may be quite complex, reflecting the complexity of the various forces that gave rise to them. Clouds often form up in long parallel lines known as *cloud streets.* They seem to be influenced to some extent by the prevailing winds. However, not all the factors involved are fully understood as yet.

A great many clouds in the atmosphere result from a combination of two or more of the processes we have described. Certain clouds, known as *airplane condensation trails,* are man-made. They are produced by moisture from the exhaust pipes of planes. Each liter of gasoline that is burned as the airplane wings its way through the skies adds a liter and a half of vapor to the air. When the gases of explosion are hurled into a subzero atmosphere, the chances are that they will instantly condense and cause a persistent trail of thin cloud to be formed.

Masses of cloud often become associated with the *jet streams*—swiftly moving

currents of air high up in the atmosphere. These clouds may either resemble airplane condensation trails or linear accumulations of mass along the path of the jet stream.

LONG-LIVED CLOUDS

At one time, meterorologists believed that clouds literally "floated" in the sky, and that the water was in the form of bubbles rather than droplets. Actually, clouds do not float in the ordinary sense. The droplets of water or crystals of ice composing the cloud are generally falling or evaporating. The overall shape of the cloud may be preserved for a time because other droplets or crystals keep replacing those that have been lost. The water drops and ice crystals are also sustained by upcurrents of air that keep them from falling. The total amount of water in a large storm cloud may weigh hundreds of thousands of metric tons. Clouds are destroyed or dissipated by evaporation, precipitation in the form of rain or snow, or by the winds.

A striking example of persisting clouds is the so-called *orographic*, or mountain, cloud. This formation, fed by updrafts of damp air rising up the slopes, may hang around a mountainside or mountaintop for long periods of time, even when winds are blowing that would move other kinds of clouds away. The famous cloud known as the "Tablecloth," which hangs over the edge of Table Mountain near Cape Town in South Africa, retains its shape and size for days at a time, although its lower edge keeps dripping rain.

Not all clouds are composed solely of water. Vast dust clouds are often raised by winds. The funnel-shaped cloud of the devastating tornado is a mixture of water droplets, dust, and various kinds of debris.

CONDENSATION

Rain, snow, and other forms of precipitation are derived from the condensed water vapor of clouds. But what would happen if there were no particles in the air upon which the water vapor could condense?

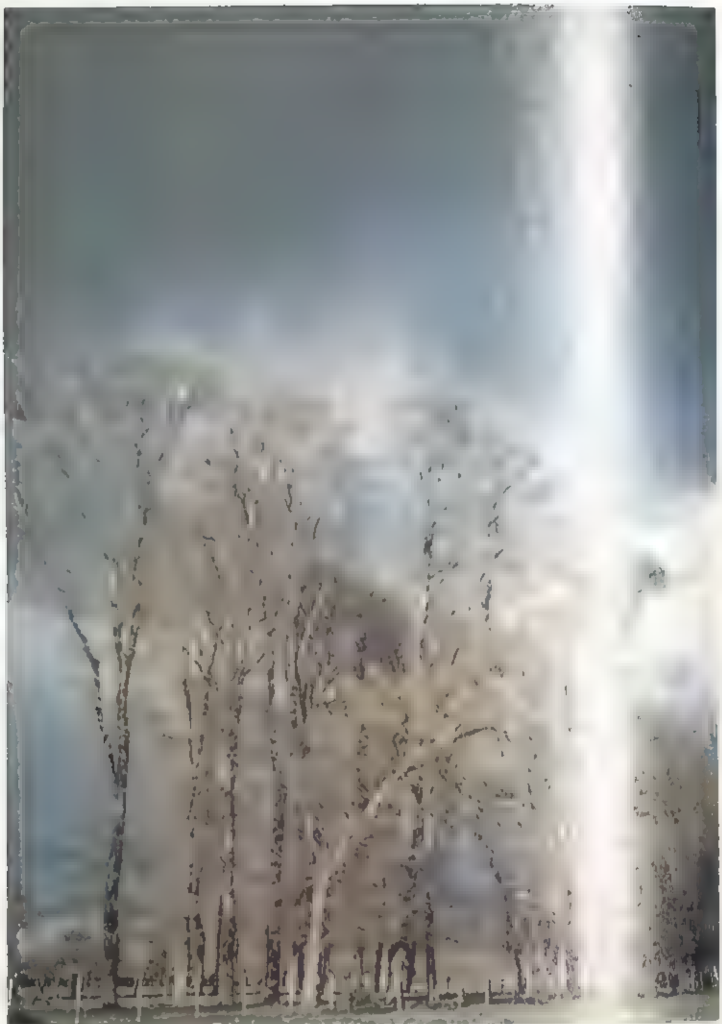
The condensation of atmospheric water vapor on mountaintops and hilltops would cause a partial vacuum to be created

Richard W. Brooks/Photo Researchers

Meteorologie nationale, Paris

© 1977 David Barnes/Photo Researchers

Two clouds of the middle-cloud family: altocumulus (top) and altostratus (middle) and one cloud of the low-cloud family: nimbo-stratus.

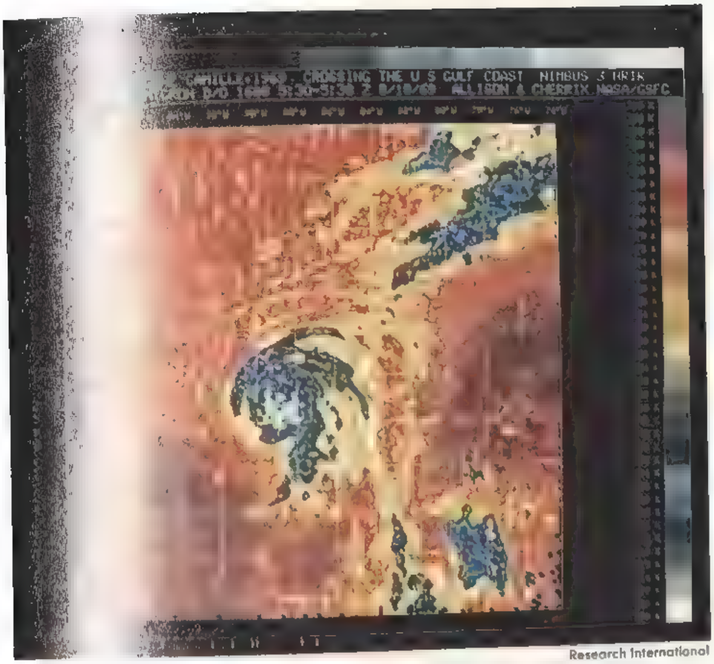

d. Fotogram

After a storm, cloud formation of cumulo-nimbus clouds obscures the sky.

there. Moisture-laden winds would be drawn to these areas, instead of the plains. The plains would be deprived even of dew and their vegetation would die. They would soon become desolate, barren deserts.

The presence of dust in the atmosphere, therefore, serves to render our planet habitable. Constant supplies of dust are belched from volcanoes or torn by the winds from the deserts of the world, as well as from the topsoil of once fertile regions subjected to continuous drought. Smoke from countless chimneys contributes its quota. Meteoritic dust entering the atmosphere from outer space may also serve as nuclei for cloud formation.

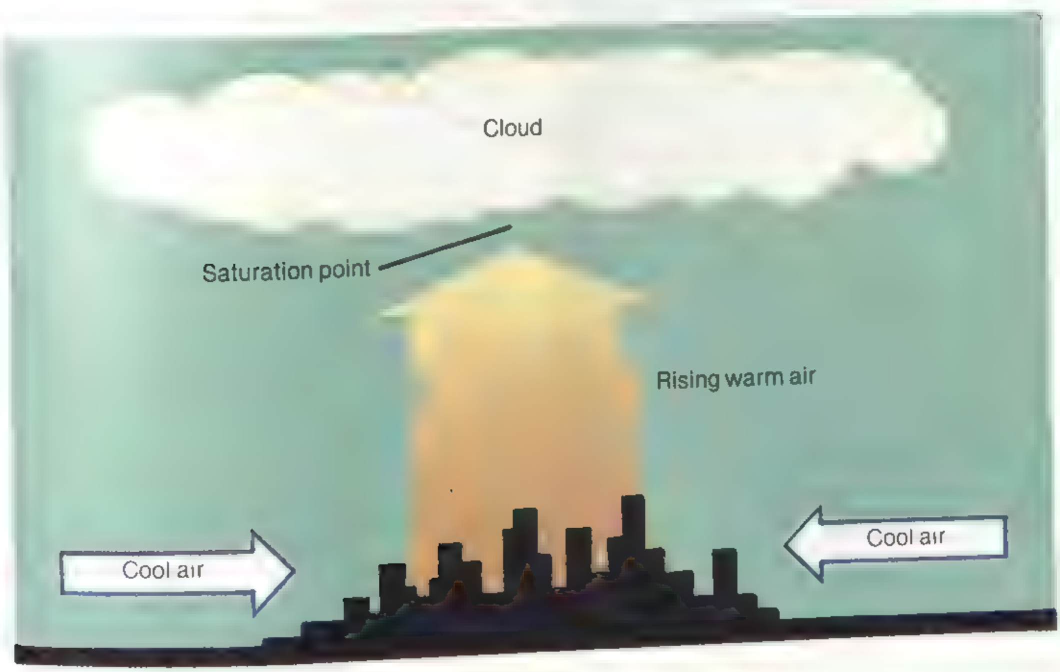
Not all clouds condense into drops large enough to produce rain, nor does all the rain produced by clouds reach the earth. In the Karroo, an extensive plateau in South Africa, rain-bearing clouds accumulate day after day in the dry season. The sky is darkened with these heavy, lowering formations, which seem almost to touch the tops of the *kopjes*, or hillocks; but the great cloud army passes over the area and not a drop of rain reaches the earth. And yet the clouds may have contained enough moisture to make the desolate Karroo fertile if this moisture had reached the earth in the form of rain. The factors responsible for this cloud behavior are not understood.



Research International

Satellite photograph, color coded, of a storm over the Gulf of Mexico. Each color represents clouds at a different altitude, and gray the "eye" of the storm.

On a l[illegible]mer day, a town is warmed by the rays of the sun. The temperature of th[illegible] the town rises above that of the surrounding countryside. The warm [illegible] rises and its place is taken by cooler air. This cooler air is warmed in its tur[illegible]ually the rising air gets cooler; finally it reaches the saturation point [illegible]ater vapor in the air then condenses, a cloud is formed



CLOUDS CONSERVE HEAT

Clouds serve other purposes besides storing up water vapor which may later be released to the earth. Among other things, they help to conserve the heat that is radiated from the surface of the earth after it has been warmed by the sun. A continuous layer of heavy clouds will, of course, cut off a good deal of the heat and light derived from the sun.

The sun emits waves of varying length which penetrate substances to different degrees. Most have some heating effect—some more than others. The radiant heat from the sun easily passes through the atmosphere and the clouds and is absorbed by the soil or surface water. The warmed earth then emits radiant heat in its turn. The heat waves it radiates are too long to pass through the clouds and are therefore reflected back to earth. If the day is sunny, clouds in the sky act as a mirror. They reflect back the heat that otherwise would escape from the earth's surface.

Stratus clouds obscuring the Eiffel Tower in Paris.

Meteorologie nationale, Paris

COLOR IN THE CLOUDS

How does it happen that the clouds take on particularly beautiful colors in the early morning and evening sky? They would not be colored at all if it were not for the molecules of air and the particles of dust and other substances in the sky. The white light of the sun, like all white light, is made up of all the colors of the rainbow. The air molecules and the particles in the higher sky are of the right size to scatter the blue light, which is part of sunlight, more than the light of other wavelengths. That is why our daytime sky is blue. When the sun is close to the horizon, at dawn and dusk, the light passes through the lower atmosphere, which contains larger atmospheric particles. These are of the right size to scatter the longer waves of light—the various shades of orange and red. It is this scattered light of longer wavelength that makes possible the brilliant colors of the clouds.

Among the most beautiful and mysterious of clouds are the so-called *noctilucent*, or *"night-shining," clouds*. They usually appear in summer at twilight as faint, billowy, silver-blue masses. They are confined to the higher latitudes of the Northern and Southern hemispheres, somewhere between 45 and 80 degrees. Their usual height above the earth is about 75 kilometers. Recent research with sounding rockets appears to indicate that noctilucent clouds are composed of tiny crystals of ice coating meteoritic dust that enters the earth's atmosphere from outer space.

FORMATION OF DEW AND FROST

Not all the atmospheric water vapor that condenses is found in fog or cloud. It is also present in dew and frost. For centuries, scientists had no true conceptions of how dew was formed. We realize now that *dew* is simply water vapor that has condensed on cold surfaces. During the day, the ground is heated by the rays of the sun. At night, if the air is clear, a good deal of

this heat escapes. The soil, therefore, is chilled, and it cools the air that is in contact with it. When the temperature of the air has been lowered below the dew point, water vapor begins to condense in the form of tiny droplets, not only on the ground itself, but also on the leaves and stems of plants.

When dew is formed at a temperature below the freezing point of water, the condensed moisture forms tiny ice crystals, and then we have the deposit known as *hoarfrost*, or *rime*, or simply *frost*. Frost forms upon windowpanes in very cold weather. The moisture in the room crystallizes as it comes in contact with the thoroughly chilled glass. The frost designs found upon panes are astonishingly varied because of the multitude of tiny scratches and dust particles on the panes, and because of air currents that modify the shape of the frost patterns as they are being formed.

RECENT CLOUD STUDIES

The use of powerful light beams to investigate the altitudes and characteristics of clouds has been practiced for many years by means of instruments called *ceilometers*. However, it is impossible to penetrate very heavy clouds with ordinary light beams because the light is easily scattered. With the development of lasers, the situation has changed. A laser emits a beam of highly coherent light—that is, light of a limited range of wavelengths and highly penetrating. Ceilometers using laser beams now exist. A device making use of laser light to investigate or detect distant objects, much as radar makes use of radio waves for the same purpose, is called a *lidar* (from "*L*ight *D*etection *A*nd *R*anging"). Recently the lidar has been applied to the study of clouds. Although the device is still only in its beginnings, it has already proved highly capable in providing data on the height, density, and distances of cloud formations. Even masses of atmospheric moisture invisible to the naked eye have been detected with lidar.

Radar, of course, has been used for a number of years in tracking the movements of storms and hurricanes. Radar has also

Meteorologie nationale, Paris

Three low-lying cloud types: strato-cumulus (top), cumulus (middle), and cumulo-nimbus (bottom). None of these cloud types is usually found above a height of two kilometers.

Atlas Photo

A heavy layer of clouds hangs over the plains of Kenya, where changing temperature and humidity favor storm formation.

shed light on the processes that cause precipitation from clouds. The larger water drops can be detected by microwaves. It was believed at one time that only the presence of ice crystals in a cloud could lead to the formation of raindrops. But precipitation has been found, through the use of radar, to take place at temperatures far above freezing.

Weather satellites moving in various orbits around the earth provide continuous data and photographs relating to cloud patterns and movements on a global scale. This has made weather forecasting far more accurate than was possible with the techniques available in former years.

CLASSIFICATION OF CLOUDS

The first serious attempt to classify the different cloud formations was made by an Englishman, Luke Howard, in 1803. He recognized three basic types of clouds: (1) stratiform (layer-shaped); (2) cumuliform (heap-shaped); and (3) cirriform (fiber-shaped).

In 1894, the International Meteorological Committee divided cloud shapes into ten classes, and with certain modifications this arrangement still prevails. According to the present internationally recognized classification, the ten cloud forms are as follows: cirrus, cirrocumulus, cirrostratus, altocumulus, altostratus, stratocumulus, stratus, nimbostratus, cumulus, and cumulonimbus. Each class is associated with a characteristic shape and amount of precipitation. The ten types are generally grouped into four families according to the average altitude of the cloud formations. The table on the opposite page gives a description of each cloud type and the symbol used to identify it.

CLOUD TYPES

Cloud ty and sym	Description	Possible precipitation	Comments
HIGH-CLOUD FAMILY—average height, 6 to 12 kilometers			
Cirrus (Ci)	Detached clouds of delicate, fibrous structure, often silky-looking, generally white in the daytime. Appear in isolated tufts, plumes, or long strands.	None	Ci are often colored bright red or yellow before sunrise or after sunset.
Cirro-cumu (Cc)	Layers or patches composed of thin ripples, small tufts, or globular masses, white in color, without any darker parts.	None	Cc are relatively rare and are always associated with Ci or Cs.
Cirro-stratus (Cs)	A thin, whitish veil that does not blur the outlines of the sun or moon. Cs may give the sky a milky look or show a fibrous structure. When sun shines through Cs, it casts shadows on the ground.	None	Watch for a halo when Cs drift in front of the sun or moon. The halo is a large rainbowlike ring with red inside and blue outside.
MIDDLE-CLOUD FAMILY—average height, 2 to 6 kilometers			
Altocumu (Ac)	One or more nonfibrous layers or patches composed of sheets, rounded masses, or rolls, which may or may not be fused or shaded.	Wisps of rain or snow called virga	A corona forms when Ac pass before the sun or moon. The corona is a small, colored ring with blue inside and red outside.
Altostrat (As)	A sheet or layer of a fibrous, striated, or uniform aspect, rather gray or bluish in color. If the sun or moon shines through As, it does not cast shadows and seems to be shining through ground glass.	Light rain or snow	As are differentiated from Cs by darker color and absence of halo or shadows on the ground.
LOW-CLOUD FAMILY—average height, 0.8 to 2 kilometers			
Strato cumu (Sc)	One or more nonfibrous layers or patches, composed of large, sometimes soft sheets, rounded masses, or rolls, grayish with darker parts, with distinctly visible outlines.	Light to heavy rain	Sc have a wavy appearance when they cover entire sky. Sc may be distinguished from Ac by absence of corona and by larger size of cloud elements.
Stratus (St)	Uniform clouds of indefinite shape, with some lighter parts but little or no relief, giving the sky a hazy appearance	Drizzle	The outlines of the sun or moon can be seen through a thin layer of St Stratus clouds become fog if they rest on the ground.
Nimbo-stratus (Ns)	A low, dark gray, shapeless, and wet-looking cloud layer that appears to be feebly illuminated from within.	Steady rain or snow	Low, ragged clouds or bad weather are often present below a layer of Ns and may merge with it.
VERTICALLY DEVELOPED FAMILY—average height, 0.5 kilometers			
Cumulus (Cu)	Dense, vertically developed clouds shaped like domes or towers, with rounded protuberances that are brilliantly white in color when lit by the sun. Their nearly horizontal bases are dark.	Infrequent light rain or snow	Over land, Cu generally appear in the morning and dissolve toward evening.
Cumulo-nimbus (Cb)	Massive, vertically developed clouds rising in the form of cauliflowerlike mountains, whose upper parts are fibrous and often spread out in the shape of an anvil.	Heavy rain, snow, or hail	Thunderstorms are accompanied by gusty winds and heavy static on AM radios.

RAIN, SNOW, AND OTHER PRECIPITATION

The sky fills with clouds, which become heavier and darker. Soon drops of rain come splashing down on the ground, trees, and buildings. If the weather is really cold, snow or a mixture of snow and rain—*sleet*—falls instead. At other times, the moisture may freeze completely to form pellets or even balls of ice, called *hail*.

What we have described is known as *precipitation*. Rain, snow, sleet, and hail are various forms of precipitation—liquid or solid water coming down from high in the atmosphere.

The water in our atmosphere is often in the form of an invisible gas, or vapor. Much of this water has been evaporated from oceans, lakes, and streams, often by the heat of the sun. Water vapor also comes from volcanic sources and from vegetation. It also comes from the exhaled breaths of human beings and animals.

THE ATMOSPHERE HOLDS WATER

The atmosphere can hold a certain amount of water vapor at a given temperature. The higher the temperature, the more water the air can contain. When it can absorb no more water at a given temperature, the air is said to be *saturated*.

If the air is chilled, it approaches its saturation point for water vapor. If this point is reached, some of the water vapor begins to condense into tiny droplets around airborne dust, tiny salt crystals, or other electrically charged particles. These water droplets may then be seen as mist or fog along the ground and at low altitudes, or as clouds at heights of a kilometer or more above the ground.

When the air temperature is below freezing, the water vapor may pass directly into the solid state, forming ice crystals. Some clouds are made up entirely of very small ice particles. Others are made of water droplets or of both water and ice.

Many droplets and ice particles are light enough to float in the air. But many others fall very slowly toward the ground. They often evaporate completely long before they reach the earth.

Should there be rising air currents in a cloud, the droplets rise and also bump into each other. Many stick together and thus become larger and heavier. These droplets therefore rise more slowly. They also fall more quickly when the air currents can no longer support them. The droplets then become full-fledged drops. If there are many and they are heavy enough, they fall as rain or some other form of precipitation, such as snow or hail.

AMOUNT OF PRECIPITATION

The type, amount, and distribution of precipitation depend not only on climate, but also on the physical features of land and sea. Despite certain exceptions, we may lay down the following general rules.

There is likely to be more rainfall in tropical climates than in other areas. The reason is the increased heat near the equator, which causes more evaporation of water.

There is often more rain near the sea than there is inland. The land and the sea are often at different temperatures. At times, there is a breeze blowing off the land. At other times, there is a wind from the sea. Sea winds may contain much moisture. If the air becomes cool enough, this moisture condenses into fog, clouds, or rain. However, there are exceptions.

Where prevailing winds contain little moisture, even a coastal area may be a desert. This is the situation, for example, along the western coast of South America, particularly in Chile and Peru. It may also occur where the water or the climate is cool.

Other things being equal, the rainfall increases with the height above sea level,

up to heights not exceeding ordinary cloud level. This is due to the action of mountains in condensing the water vapor contained in the winds that blow over them. The average rainfall of the plains of Europe is 57.4 centimeters per year. In the mountainous districts it is over 125 centimeters. Along the western slope of the Rocky Mountains in the United States, the precipitation is abundant, reaching a total of some 340 centimeters a year in certain localities. In the interior of the United States it is much smaller. It is less than 40 centimeters a year in some states.

The rainiest regions of the world are probably the lower slopes of the Himalayas. The village of Cherrapunji, India, south of the main body of the Himalayas, has an annual rainfall averaging 1,082 centimeters. A record-breaking twelve-month rainfall of 2,646.12 centimeters occurred at Cherrapunji from August 1860 through July 1861, and in August 1841 no less than 3,800 centimeters of rain fell in a five-day period—the equivalent of almost four years of rainfall in New York State.

The ascent of moist air blowing across a mountain range also accounts for the heavy rainfall in the coastal region of British Columbia, Canada, and for the average annual rainfall of 1,175.84 centimeters near the top of Mount Waialeale, in central Kauai, Hawaiian Islands. This type of precipitation is known as *orographic rainfall* (from the Greek word *oros*, meaning mountain). Because time must elapse between the beginning of the lift of the vapor-laden air masses and the actual fall of rain, the greatest orographical rainfalls are generally found part way up the mountain slopes. If the mountains are low, rain may fall in great quantities beyond the crests of the ranges. There may be as much rain on the far side as on the near side. If, however, the ranges are high, precipitation is greater along the windward slopes.

WET AND DRY SEASONS

The heavy rainfalls in the tropics are due not so much to condensation of moisture by mountain ranges as by the effect of cold winds pouring in from cooler regions.

Sleet, or rain mixed with snow, can be very damaging. Sleet has covered these wires, and the weight of the iced wires is great enough to break some poles.

A T & T Photo Center

The line of meeting moves north and south with the movement of the sun. When the sun is north of the equator, the cloud belt is in the Northern Hemisphere. When the sun is south of the equator, the cloud belt is in the Southern Hemisphere. The cloud belts are easily visible from space and from the moon, as photographs and television pictures from spacecraft have shown and according to the testimony of astronauts. The clouds may be so dense as to obscure the familiar geographic features of the earth. The cloud movements from Northern to Southern hemispheres and back again cause the tropical wet and dry seasons.

In the temperate zones there are no clearly defined wet and dry seasons. The lifting of moist air by revolving storms, or cyclones, may bring about precipitation in these areas. Cyclones form a variable pattern on the weather map as they advance. The rainfall patterns resulting from them show far more variation than those of orographic rainfall. When rainfall results, it is apt to be spotty. The same rainfall may drench one community and barely settle the dust a few kilometers away.

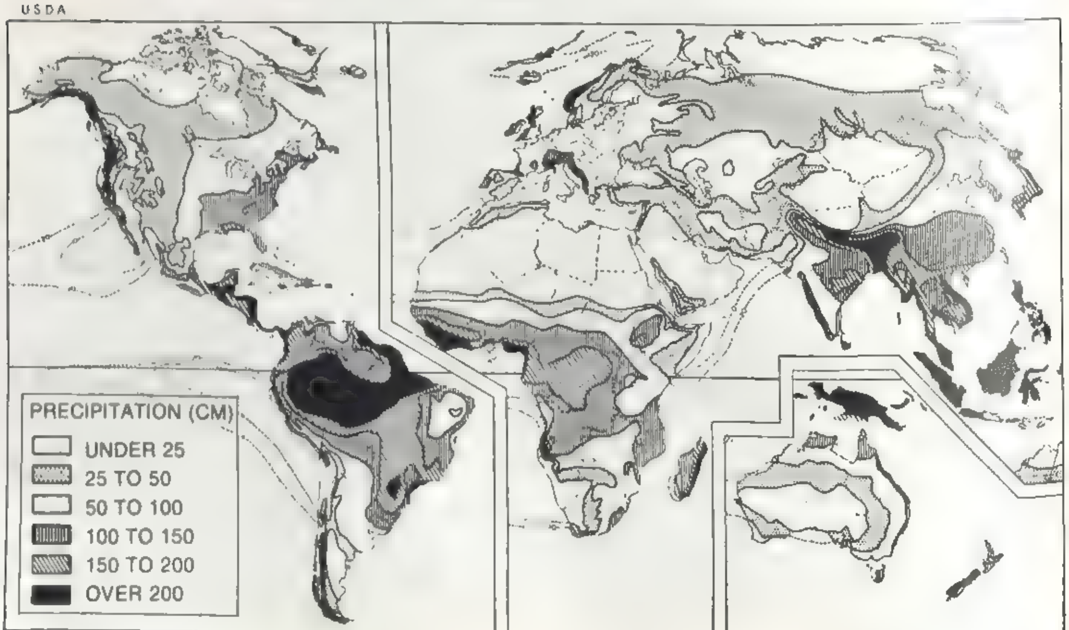
SOME VERY DRY AREAS

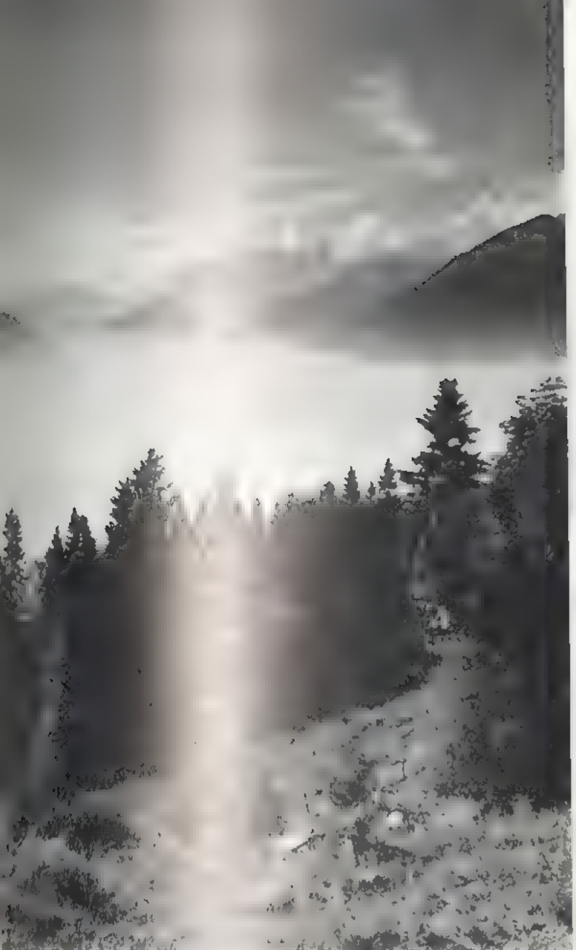
In certain regions of the globe there is almost no rainfall. Very seldom does it rain in the districts to the south and east of the Caspian Sea; in the Karroo, a plateau area in the Union of South Africa; in the southern part of Australia; and in the canyon region of Arizona, in the United States. Parts of Peru and Chile are also quite rainless. There is practically no precipitation in a belt of land, about ten degrees wide, which extends across Africa, northern Saudi Arabia, and Iran, and ends near western Afghanistan. Rain never falls in areas of the Gobi, in central Asia.

If there is only a small amount of rainfall, it may be vitally important. In the forbidding table lands of the Karroo, vegetation dies when there is a long dry spell. Deaths among sheep and other animals are great. When the rains come, the response of vegetation to the moisture is almost miraculous. The French geographer Reclus gave a graphic account of the effects of the dry and rainy seasons upon the soil of the Colombian llanos, or plains. "The watercourses,"

Diagram showing how precipitation (rain, snow, sleet, hail, and so on) is distributed over the face of the earth.

USDA





Fritz Henle, Photo Researchers

As water vapor in the atmosphere begins to condense into tiny droplets, it becomes visible as mist or fog along the ground or as clouds at altitudes of a kilometer or more.

U S Forest Service

A well-watered region—such as this in Utah, which benefits from rain-favoring conditions of nearby mountains—supports lush vegetation and rich farming areas.

he wrote, "become exhausted [in the dry season]; the lakes change into pools and then into sloughs. . . . The clayey ground shrinks and cracks; the plants wither and are torn to shreds by the winds. The cattle [are driven] by hunger and thirst. . . . and multitudes of their skeletons lie bleaching in the plains. . . . All at once the storms of the rainy season inundate the soil. Multitudes of plants shoot out from the dust, and the yellow expanse is transformed into a flowery meadow."

EFFECTS OF TREES AND TEMPERATURE

It has been maintained that trees bring rain and that the felling of forests decreases the rainfall. There is no doubt that deforestation diminishes the permeability of the soil, and diminishes its capacity for catching and holding water. It is also known that trees can hinder evaporation of water from some surfaces because of their foliage. A road overshadowed by trees, for example, takes longer to dry out after a heavy rain than does a road running through a treeless expanse.

But trees play other roles in precipitation. Trees—particularly their leaf surfaces—release water vapor to the atmosphere by the process known as *transpiration*. In a heavily wooded area, transpiration is the source of much of the water vapor in the air—water that may later fall to the earth in the form of precipitation.

Temperature plays an important part in the process of precipitation. According

Service

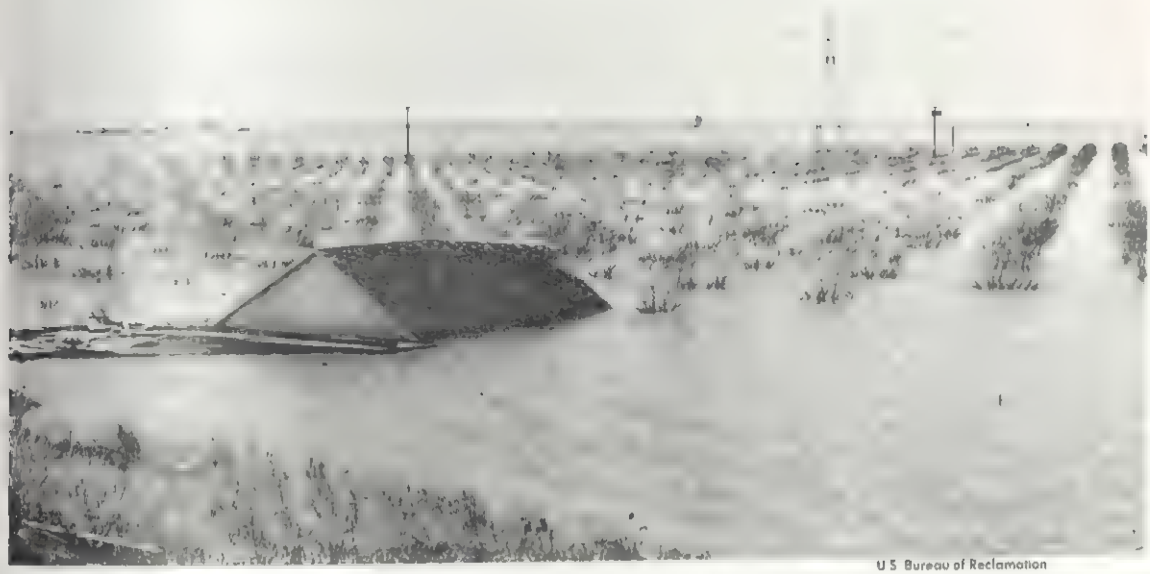
U.S. Geological Survey

Rain is responsible for the erosion of rocks and soil and often leads to very unusual formations. Top photo: fingerlike projections in soft sandstone formed by the action of rain water. Bottom photo: a stone statue carved by the rain.

to meteorologist R. Brown, "the slightest difference in the temperature of the soil over which a vapor-laden cloud is sailing may determine whether its moisture will be condensed and precipitated, or whether the misty vapor will float away without the thirsty earth obtaining the benefit of its contents, here more grudgingly bestowed than in the cooler regions near the poles." Certainly trees do not retain heat, and they are usually cooler than the soil.

Whether by favoring condensation, or through the high electrical tension characteristic of tree tops and tips forests do seem to attract rain directly. Evidence also indicates that deforestation leads to drought. In some areas, the cutting down of trees was followed by a decrease in the rainfall, and a replanting was followed by increased rainfall.

Drought brings with it the danger of forest and prairie fires. After weeks of dry weather, grass, shrubs, and trees are like tinder, ready to catch fire. Then a very small spark may kindle a destructive blaze. Sometimes even the friction of two branches against each other may kindle a flame.



U.S. Bureau of Reclamation

Flooding is a relatively common—and destructive—event in some areas. Rivers overflowing their banks because of heavy rains frequently destroy orchards and farmlands.

Forest and prairie fires sometimes spread for many kilometers.

CHEMICAL ACTION OF RAIN

Rain plays a very important part in molding the face of the earth. Its action in this particular process is partly chemical and partly mechanical.

In considering the chemical action of rain, we must bear in mind that it is not pure water. In the atmosphere it absorbs atmospheric gases—oxygen, nitrogen, and carbon dioxide. These are found to be absorbed in the following volume proportions: nitrogen 64.47; oxygen 33.76; carbon dioxide 1.77. The absorbed gases are not found in the same proportion as in the atmosphere. The carbon dioxide occurs in proportions thirty to forty times greater than in the atmosphere. Besides these natural atmospheric gases, rain also absorbs a certain amount of nitric acid, sulfuric acid, and salts. It also carries with it microorganisms and dust. As soon as it touches the earth it adds to its chemical contents.

Rain, accordingly, contains various more or less active chemical substances and has a varied chemical action on the rocks and soil on which it falls. Because it contains oxygen, it oxidizes or rusts various minerals such as iron. The organic matter it contains deoxidizes other minerals such as gypsum. And the carbonic acid it contains dissolves limestone and marble, carbonate of magnesia, and other minerals. The so-called "pipes" and "swallow holes" found in limestone rock are funnel-shaped cavities corroded in the limestone by rain. If there is no soil on the surface to fill up these holes, they deepen and may eventually become caverns.

The Karst district in Yugoslavia is honeycombed with these holes, which are locally known as *doliniens* or *dolinas*. Some of them are deep. The deepest is 160 meters. Others are relatively shallow. At the bottom is found a red earth—the insoluble iron-oxide residue of the limestone. In northern Bohemia and Saxony hollows one to ten meters deep, known as *karren* or *seh-*

ratten, are found. These doubtless are also formed by rain eroding limestone.

Even granite is rotted by water, so that it becomes loose and can be dug into with a spade. It is mixed with clay and sand. In the United States, granite in the District of Columbia has been found decomposed to a depth of as much as 25 to 30 meters. Near St. Austell, in the English county of Cornwall, huge pits, as big as skyscrapers, have been dug into the granite by miners in search of tin and china clay.

In some cases when rain is absorbed by rock, the latter forms a chemical compound with the water and undergoes the change known as *hydration*. Anhydrite, for instance, is converted into gypsum, and it increases in bulk about 33 per cent at the same time.

MECHANICAL ACTION OF RAIN

The mechanical action of rain is quite obvious. Every heavy shower of rain scours and scars dirt roads and paths with gullies. When the rain comes down in sheets it carries away the soil as effectively as a river. Where there are trees and vegetation to shield the soil and hold it together the rain may fail to remove much of it, but where the soil is unprotected it may be quickly carried away. The destruction of forests, accordingly, is bound to increase greatly the destructive effect of rain. Many parts of Syria, Greece, Turkey, Africa, and Spain have first been denuded of trees by people, and then of soil by the rain.

In some cases torrential rain produces floods of mud. A catastrophe of this kind occurred near the volcano of Vesuvius, in Italy, in September 1911.

"The torrential rains which fell caused a huge volume of mud and lava to flow down the sides of the mountain, and this, dividing into several branches, swept over the entire countryside, destroying everything in its path. The town of Resina was completely engulfed in it, and the mud gradually reached the height of the first-floor windows of the houses. To describe the horror of the scenes that ensued one would be obliged to have recourse to the most awesome incidents in Dante's *Inferno*. The floating corpses of people who had been overtaken by the terrible flood presented a dreadful spectacle. . . . Farming utensils and furniture, together with cows, horses

Severe sheet erosion has occurred on land barren of trees, grasses, and other forms of vegetation that can prevent washing away of valuable topsoil.

USDA, Soil Conservation Service

USDA, Soil Conservation Service

Soil was   rom a field was carried by runoff to the edge of the field and deposited as   ›nt

and various other domestic animals, were also caught up and borne along by the stream. The district of Miglio di Oro, one of the most enchanting parts of the commune of Resina, has been flooded with mud and totally ruined. The onrush of the stream was such that many houses were swept away bodily.

The impetuous torrent rushed down the mountainside and burst with great force against the walls of the houses. The doors crashed in and the thick stream . . . flooded the lower floors. . . . In many cases, the mud inside the houses flooded the stairs and the upper floors. . . ."

LANDSLIDES

In many cases rain destroys, not by causing deluges of mud, but by producing landslides, in which large masses of earth and rock slide bodily downhill. Rain contributes to landslides in various ways. It causes the disintegration of soil and adds immensely to its weight. It creates new debris on slopes by penetrating into crevices and cracks in rock. When freezing takes place, the ice expands and causes the surface rock to be broken up. Water also acts as a lubricant for landslides. Some landslides involve only the regolith, or mantle of loose material that lies above bedrock. In other cases, the descending material includes quantities of rock fragments that were broken off from the underlying layer as the slide passed over it.

The mass movement of weathered material on slopes may be very slow. This material will begin to descend after it has been saturated by particularly heavy rains or by melting snow. The movement may continue for many years and may cause practically no destruction. Trees may continue to grow on a slope on which a slide of this type is taking place, but they are likely to be tilted at various angles.

In some instances great masses of rock fragments, large and small, move downhill at a very rapid rate and may create havoc. One of the most destructive slides in recent centuries occurred in Italy in 1855. A mass of rock debris 1,000 meters long, 300 meters wide, and 180 meters high, roared down into the valley of the Tiber River, in the vicinity of the village of San Stefano. The

debris completely dammed up the valley, converting the Tiber River into a deep lake. San Stefano, which nestled in the valley, was submerged under 15 meters of water. There was a great deal of property damage and many persons lost their lives.

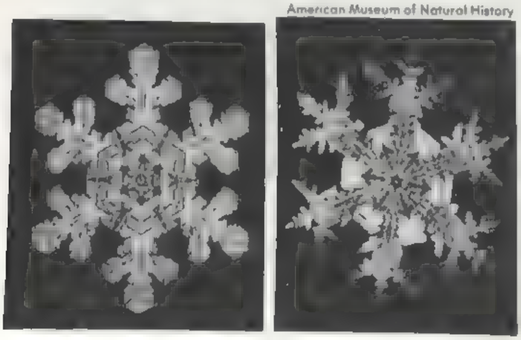
Another devastating slide took place in 1903 at Frank, in the Canadian province of Alberta. A huge volume of rock, estimated at 30,000,000 cubic meters, slid from the top and side of Turtle Mountain and went crashing into the valley floor below. Such was the momentum of the slide that its front advanced three kilometers across the valley and 120 meters up the opposite side. The entire movement lasted less than two minutes. The mass of rubble that covered the valley wiped out the town of Frank and killed seventy persons.

The Gros Ventre Valley in Wyoming, in the United States, had a memorable slide in 1925. About 38,000,000 cubic meters of debris descended some 600 meters on an underlying layer of saturated clay. As in the case of the Alberta slide, the front of the mass of debris made its way across the valley and then up the other side.

A slide (or slides) probably accounts for the curious blocks of quartzite that fill many of the valleys in the Falkland Islands. The blocks are covered with white lichen and from a distance look like small glaciers. Since they have the same structure as the quartzite ridges on the hills above the valley, it is believed that they were detached somehow, probably through the action of rain, and slid down the slope.

These photos show the delicate patterns formed by snow crystals. Each crystal has six sides or points, and no two snow crystals are exactly alike.

American Museum of Natural History



OTHER EROSIVE ACTION

Other land movements caused by rain are less dramatic, but play an important part in molding the landscape. As the loose soil masses that often form the banks of rivers are saturated by heavy rains, they sometimes slump. This type of action accounts for a great deal of the river-bank erosion that takes place in areas where rainfall is abundant.

In regions where there is little or no rain, rivers do not carve out gentle valleys, but cut steep gorges with perpendicular banks, as in the canyon country of Arizona in the United States. If this area were subjected to rainfall such as deluges Cherrapunji, India, its contours would soon be completely altered.

Snowy woods. We all appreciate the beauty of scenes like this, but snow has a far greater significance. Melting snow feeds our fresh water supply.

Rainfall produces the odd formations known as *earth pillars* or *pyramids*—tall pinnacles of earth capped by stones. They are simply columns of hardened clay. Protected by their stone capping, they have resisted the eroding power of rain, while the clay that was not so protected has been washed away. If the stone falls off, the pillar will soon be eroded to the surface of the ground. Earth pillars of this type are to be found in the Tirol in Europe, in the Himalayas, and in various other places.

SNOW

The popular idea of snow is that it consists of frozen raindrops. This is not the case. It is true that sometimes raindrops freeze in their passage from the mother cloud to the earth. Such frozen raindrops are called sleet or hail. But snow is something else again. It is made up of water vapor particles that have been transformed into crystals, without first passing through the liquid state. Such crystals can form only when the *dew point* is below 0° Celsius.

Canadian Pacific Railway

The dew point is the temperature at which a mass of air becomes saturated, when it is cooled with no change in either the air pressure or the amount of water vapor it contains.

Once the crystals have been produced, they may enlarge by combining with other crystals or with water droplets. Large flakes are generally combined in this way when the temperature is not much below the freezing point. Large flakes are never formed at very low temperatures.

Snowflakes are still a good deal of a mystery to scientists. For instance, why should every perfect crystal of snow always have six sides or six points? Why should it be flat and not round like a hailstone or raindrop? How long does it take a crystal to form? Why are no two crystals exactly alike? Wilson Bentley, of Jericho, Vermont, photographed and examined snowflakes for over fifty years, and he never found two identical flakes.

Snow can fall from almost any kind of low or middle cloud. It may come when the barometer is rising and the air pressure is increasing, or when the barometer keeps going down. There may be snow when the thermometer outside your window reads 2.7° Celsius. If it goes above that mark, the flakes will probably melt and fall to earth in the form of rain. It may also snow when it is −45° Celsius, but that does not happen very often.

To a poet snow is the subject matter for a lyric. To youngsters it means coasting and snowball fights. To their elders, it means skiing and tobogganing. But snow is not the exclusive property of poets and lovers of sports. For one thing, it is a valuable resource. The snow that accumulates in mountainous areas during the winter and gradually melts during the spring and summer is an important source of water supply. Snow also serves as a blanket that prevents the heat of the soil from escaping into the air. It keeps the roots of perennial plants and the seeds of annual plants from freez-

ing. In this way, it assures the permanence of vegetation.

Of course, a heavy snowfall can often be disagreeable or even dangerous. Heavy snow comes when warm air masses ride up over colder air masses lying in their way. If the rising air is very moist and if the wedge of cold surface air remains nearly stationary, the stage is set for snowmaking on a very large scale. It will continue to snow as long as the supply of warm, moist air lasts and as long as it is forced to ride up over the colder air mass. Under such circumstances, a rate of more than two centimeters of snowfall an hour is not uncommon. When this goes on hour after hour, it adds up to a good deal of snow.

In the United States a heavy snow with violent winds is known as a *blizzard*. Perhaps the most famous one in the history of the country struck New York on March 12, 1888. The city was buried in snow and drifts reached second-story windows. All street-car and elevated traffic stopped. Electric wires collapsed and rail and wire communication was cut off. The cost ran into many millions of dollars. Even more snow fell upon the city on December 26, 1947 – 65.5 centimeters in less than twenty-four hours. But this snowfall was not a blizzard, since the winds were moderate.

SLEET AND GLAZE

Sometimes newly formed raindrops freeze on their way to the earth. They may be mixed with snowflakes that have melted and then frozen again. This formation is called *sleet* in the United States. In England the word sleet applies either to a mixture of snow and rain or to a mixture of snow and hail.

Some raindrops freeze after they have reached the earth. Many people refer to this sort of deposit, too, as sleet, but the official name given to it by the U.S. National Weather Service is *glaze*. Glaze on a large scale is called an *ice storm*. It is a menace to everybody. It often comes unannounced.

As a matter of fact, the dividing line between snow-making and glaze-making is difficult to determine. Glaze is produced under much the same conditions as snow. A moist air mass is pushed up over a wedge of colder air. If the air aloft is cold, there will be snow. If it is warm, rain will start to fall.

Suppose now that the wedge of underlying cold air is shallow and that the raindrops have only a short distance to fall before reaching the ground. In that case the chances are that the drops will not begin to freeze until they hit something cold, such as the limb of a tree, or a telegraph line or the ground itself. Every exposed object gets a coating of ice. Given time, the coating process may go on until the layer of ice that has formed will be thick enough to weigh down and break the branches of trees. Humans and animals will flounder helplessly on the icy surface of the ground. Small birds may have their feet frozen to the branches of trees; the wings of others may be frozen solid.

The ice storm that swept over New England in November 1921 did a good deal of damage in certain places. The damage to trees was particularly heavy. Orchards were ruined and forests were badly mutilated. Nor did the immediate effects of the storm tell the whole story of disaster. The wounds inflicted on the surviving trees made them vulnerable to fungus and insects. The litter of broken branches paved the way for forest fires the following summer.

Really bad storms like this are comparatively rare, both in Europe and North America. The most frequently affected area in North America runs westward from the New England and mid-Atlantic coast through the Central Lowlands to Nebraksa, Kansas, and Oklahoma.

FORMATION OF HAILSTONES

A particle of sleet and a hailstone may look much alike, but there is a difference. Sleet is simply frozen water. A *hailstone* is a much more complicated object, with alternating layers of snow and clear ice. There are other differences. Hail forms inside thunderclouds instead of underneath warm air fronts. It is a summer visitor, while sleet is more apt to fall in the winter months.

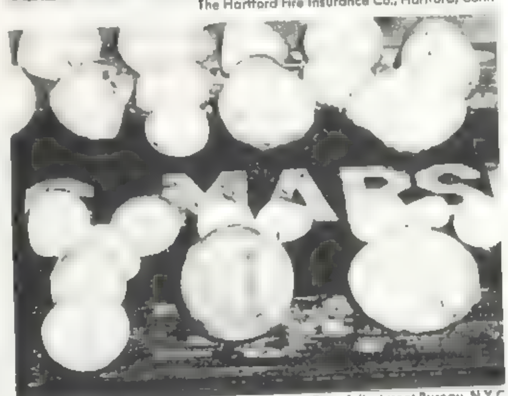
Hail may form as water droplets freeze in the upper air. As the hailstones fall, they grow by thickening the cooled water drops through which they pass lower down and collecting them as additional ice layers. According to another theory, hail is created as raindrops, which, instead of falling, are carried by winds into the upper atmosphere, where they are covered with snow. When the winds fail to hold their increasing weight, the pellets start to fall. They tumble back into the above-freezing cloud levels and get a coating of raindrops. The stones, which have now become hailstones, may be caught up in another upcurrent and blown back into the snow region again. There the newly acquired water coating freezes into clear ice and the stones get another wrapping of snow.

Under favorable circumstances, this repetitive motion can go on for a long time. Of course the hailstones get bigger with every completed up-and-down movement. Hailstones have been found with as many as twenty-five alternating layers of snowy ice and clear ice. Just cut open a newly fallen stone sometime and see for yourself. If you divide the number of layers by two, you will have the approximate number of up-and-down journeys made by the stone.

Only a thunderstorm can produce hailstones but very few actually do. The figure is something like one out of four hundred. We may be thankful for that, for hail is a troublemaker. A single hailstorm can cause several million dollars' worth of crop damage when it comes, as it generally does, about midsummer. All this damage is likely to be concentrated in a strip of land seldom more than 40 kilometers long and 10 to 20 kilometers broad. You can easily see why some farmers speak of "hellstorms" and why they are such firm believers in hail insurance.

Most of the damage done in a hailstorm is done by pellets no bigger than peas. Occasionally hailstones are as big as baseballs. A baseball is a little less than eight centimeters in diameter. When such hail falls, greenhouses and roof tiles are smashed to bits and men and animals may be literally stoned to death. The records tell us that on July 10, 1923, hailstones killed twenty-three people and many cattle near Rostov, in the Soviet Union.

The Hartford Fire Insurance Co., Hartford, Conn



Shoopman Gen. Adjustment Bureau, N.Y.C

Top: typical hailstones. The top ones have been cut in half to show the alternating layers of ice and snowy ice. Bottom: unusually large hailstones. Compare them with the baseball.

Under particularly favorable circumstances, hailstones may become as big as good-sized grapefruit. Stones of this kind fell on the town of Potter, Nebraska, on the afternoon of July 6, 1928. One of the giant stones was weighed, measured, and photographed immediately after it had fallen. Its weight was found to be about 680 grams, and it had a diameter of about 13 centimeters. This was the largest hailstone of which we have definite record. Imagine how many times it must have been tossed up and down.

WATER IN THE GROUND

by Oscar E. Meinzer

There is more water in the world than we can see in oceans, lakes, ponds, and streams. A good deal is contained in the pores and cracks of the soil and rocks under the surface of the earth. This *ground water*, or subsurface water, as it is called, feeds springs, brooks, and rivers and supplies wells. If there were no ground water, some streams would be dry except after a heavy rainstorm or immediately after the melting of snow. In many places the only water supplies would be those obtained by impounding storm waters or catching rain water in storage tanks.

What is the source of ground water? This question once puzzled the most learned men. Before the latter part of the seventeenth century, it was generally assumed that the water discharged by springs could not be derived from rain. It was believed that there was not enough rainfall for this purpose. Besides, the earth was supposed to be too impervious to permit rain to penetrate far below the surface.

SOURCES OF GROUND WATER

Various ingenious hypotheses were offered to account for the presence of the water that fed streams and emerged from the earth in the form of springs. The favorite theory was that sea water was conducted through subterranean channels below the mountains. It was then somehow purified and raised, finally penetrating to the surface. This theory was not fully discredited until the seventeenth century Frenchmen Pierre Perrault and Edme Mariotte made crude measurements of rainfall and stream flow. They showed that rainfall is ample to supply springs and rivers.

Today we realize that most ground water is derived from rain and snow and other forms of precipitation. There are several other possible sources, it is true. At the time when sediments were laid down on ocean or lake bottoms, water filled the spaces between the grains of materials such as sand and silt. The deposits were transformed into sedimentary rocks in the course of the ages. Water was trapped in these rock formations and some of it still remains there. Ground water may originate, too, from the steam rising from magmas—molten rock materials—deep within the earth. But the water trapped in rock

Wyckoff

formations and that derived from magmas make up a very small part of the total quantity of ground water.

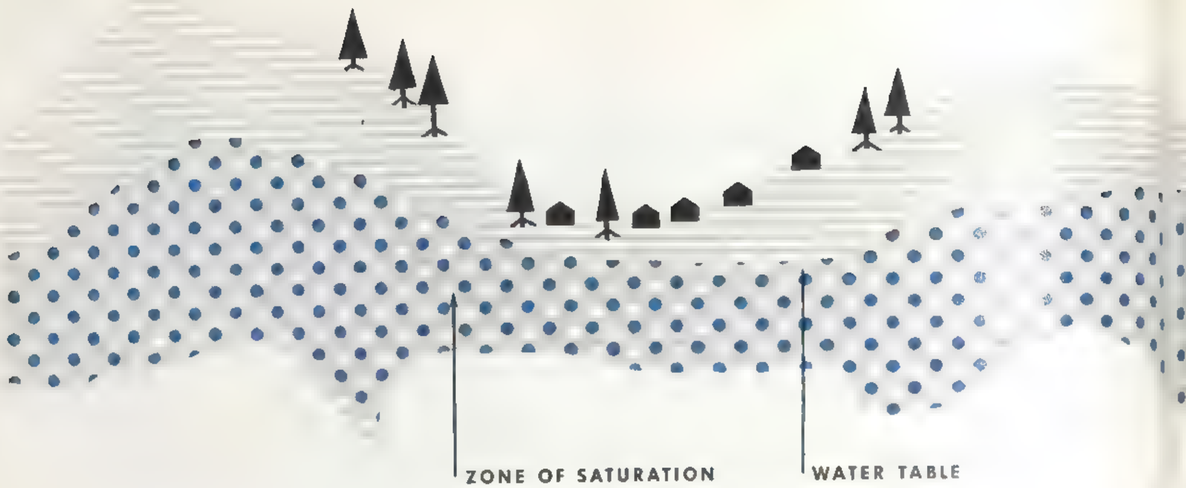
AMOUNT OF GROUND WATER

The amount of precipitated water that will seep into the ground from the surface will depend on various factors. Of course an important one is the total amount of precipitation. The rate of precipitation is also important. When rainfall is heavy, the surface quickly becomes saturated and water flows along the surface instead of making its way into the ground. The slope of the land on which rain falls is another determining factor. The steeper the slope, the greater the surface runoff will be.

The porosity of the rock through which water must pass also helps determine the water content underground. Porous rocks have various openings into which water can penetrate. These openings may be spaces between pebbles and grains in deposits of gravel and sand or between grains in indurated, or hardened, rocks. Cracks and fissures may be produced by the fracturing of hard, brittle rocks, such as sandstone, quartzite, slate, and granite. Crevices may form in rocks such as limestone, as percolating water slowly dissolves them. Gaps may be produced by the weathering of rocks near the surface. The porosity of a given formation represents the ratio of its empty spaces to its total volume. It ranges from less than one per cent in the case of certain igneous rocks, such as granite, to more than 40 per cent in certain sands and gravels.

Water can leave the ground as a solid, liquid, or gas. Opposite page: ground water emerging from rock crevices at freezing temperatures forms ice on the cliff face. Near left: water emerges from the ground as steam, forming hot springs.

Verna R. Johnston, Audubon/PR



This drawing shows the zone of saturation, where all the rock openings are full of water. The water table is the upper boundary of this zone.

The rate at which water will sink into the ground will also depend upon the permeability of the formation through which the water passes. When we say that rock or soil is permeable, we mean that it permits water to pass through it. Permeability is not the same thing as porosity. Two rock formations may be equally porous. Yet one will permit water to pass through rather easily, while the other will be almost impermeable. The arrangement of coarse-grained and fine-grained particles within the formation may be the deciding factor. Coarse-grained gravel mixed with fine-grained particles may be less permeable than gravel not so coarsely grained but with fewer fine-grained particles. A clay formation may be very porous; yet when it is saturated, it will be impermeable. Since the pores in clay are tiny, the water in the pores will be held by the molecular attraction of the clay particles.

The nature of the rock strata is another factor in the descent of water. If a given rock stratum is flat, it will be harder for water to make its way downward than if the stratum is inclined. The descent of the water will also be influenced by the presence of vegetation at the surface. Forests and grassy tracts hold back runoff following heavy rains. The result is that more water sinks into the ground. Finally, the amount of water vapor in the atmosphere will help determine how far downward water will penetrate. If the humidity is low following a rainfall, much of the rain water will evaporate before it can sink below the surface. In desert areas, most of the precipitation that has been yielded up by the atmosphere is returned to it again in a comparatively short time as the water evaporates.

ZONE OF SATURATION

The water making its way downward through porous and permeable rock formations finally reaches a *zone of saturation*. This is a region in which all the rock openings are full of water. The upper boundary of the saturation zone is called the *water table*, or the *ground-water level*. Unlike the surface of rivers or lakes, the water table is not level. It is higher in some places than in others, depending upon the general contour of the land surface. For example, the water table is higher under a mountaintop than it is in the valley below. However, it would lie deeper below the surface at the mountaintop than it would at the valley.

In most cases the water table slopes downward toward a stream. As the upper limit of the zone of saturation lies above the stream, the zone supplies the latter with water through seepage and springs. In an arid region, the water table slopes upward toward the stream. The saturation zone lies below the stream. Water seeping from the stream replenishes the ground water beneath it.

Usually the water table slopes downward toward a stream (shown above in cross section). The zone of saturation supplies water to the stream.

A body of water trapped in porous and permeable materials may be suspended above the main water table. This happens when ground water is prevented from sinking any farther by a mass of impervious rock or by a basin-shaped bed of clay. The water trapped in such a formation is called a *perched water body*. Its upper level is known as the *perched water table*. Water that has been trapped in this way is usually found in arid or semiarid country. It often furnishes a valuable water source.

The character of the rock formations will determine how deeply surface water will penetrate into the ground. This represents the bottom limit of the zone of saturation. In some places it is one hundred meters or more below the surface; in other places, one thousand or more meters. It is believed that at a depth of several kilometers the pressure of the overlying rocks is so great that there are no open spaces in the rocks. Therefore, their porosity and permeability are nil.

WATER CIRCULATION AND TEMPERATURE

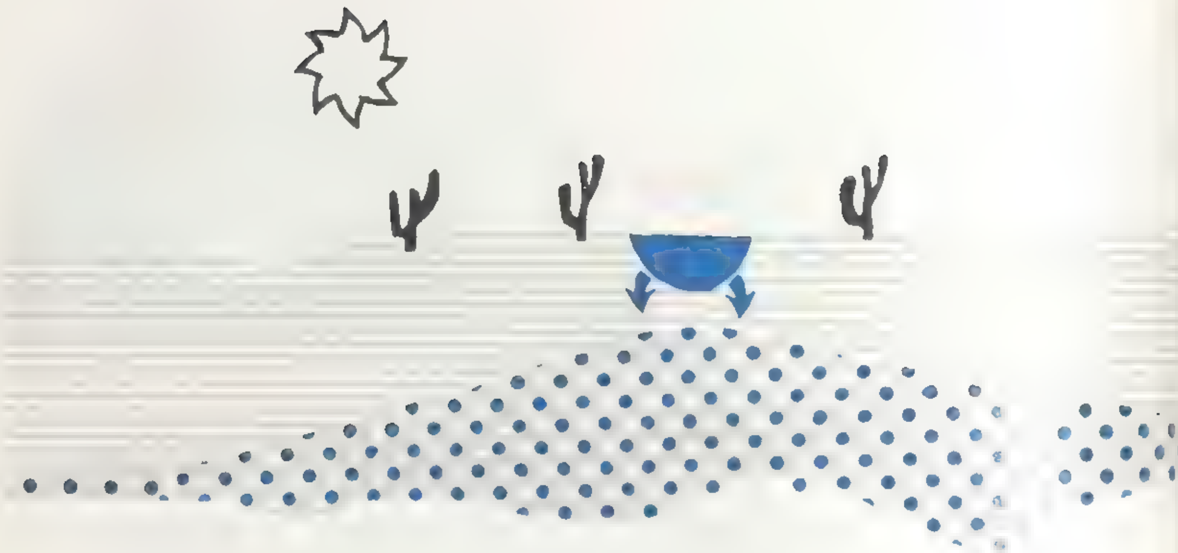
The ground water above the zone of saturation descends because it is drawn by the force of gravity. However, it rarely goes straight downward. It tends to follow the path of least resistance. If some of the rock formations it encounters are very permeable and others not nearly so permeable, its course is apt to be very erratic. The downward movement of water in the area above the zone of saturation is called the *shallow*, or *vadose, circulation*.

The water in the zone of saturation also circulates. Its movement, however, is generally much slower than that of the water above it. One reason is that there are far fewer openings in the rock. The movement of water in the saturation zone is called *deep circulation*. It depends on various factors. Among these are the character of the openings in the rocks, the way in which rock layers slant, and the head, or water pressure, of the water in the saturation zone.

The temperature of ground water very near the surface fluctuates somewhat with the seasons. At depths of as much as eight meters in the temperate zones, water temperature is nearly constant. It is generally about the same as the mean annual temperature of the air, or a little higher. Ground water temperature rises with increasing depth. The rate of increase is generally about 1° Celsius for each 25 meters of increase in depth. In parts of Alaska and other arctic regions, the ground water is perennially frozen to depths of one hundred or more meters. It may thaw out near the surface, however, in the summer.

SEEPAGE AND HOT SPRINGS

When ground water makes its way to



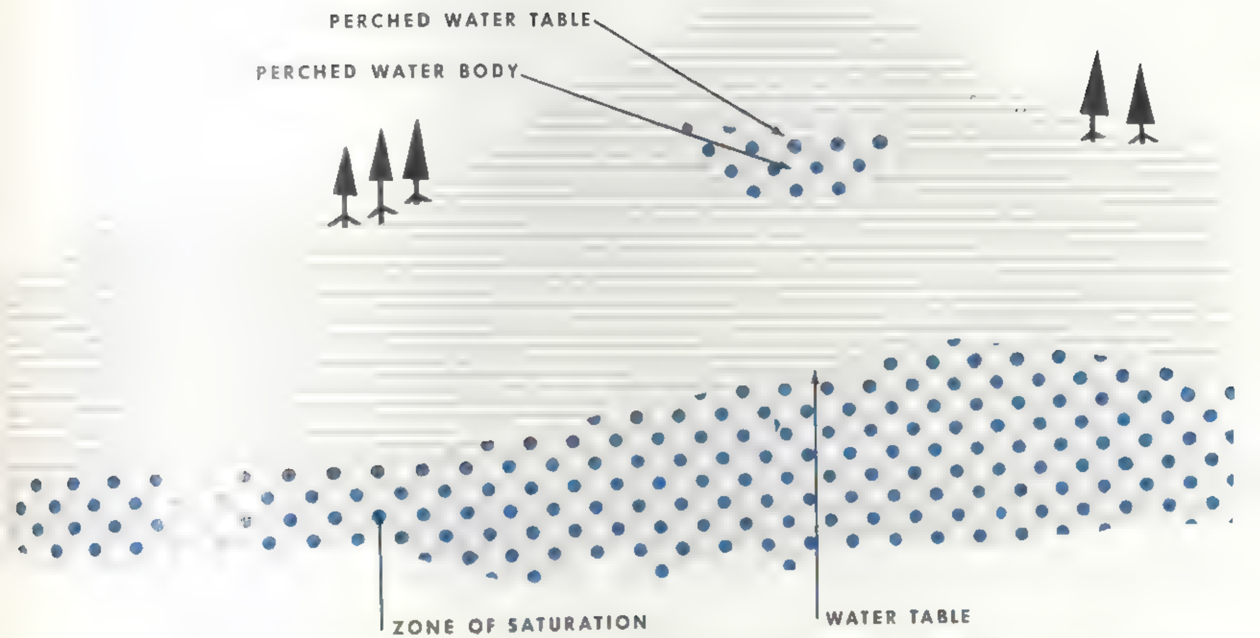
In an arid region the water table slopes upward toward a stream. Water seeps from the stream, in this case, toward the zone of saturation.

the surface through natural openings in the ground, springs are formed. In many low-lying places spring water seeps imperceptibly out of the ground. It flows from a hundred different sources and forms so-called *seepage springs*. In other places, the water may be seen rising from the soil or flowing out of crevices in rock. Certain springs are said to "boil," even though the water is cold, because the rising water stirs the clear sand in the spring basins. Large springs generally issue from deep underground pools, or from tunnels or alcoves in the rock. Occasionally springs arising from deep-seated strata may discharge fresh water on the ocean floor. A spring of this sort is found in the Gulf of Argolis, in Greece. In this area, the fresh water issues with such force that the surface of the ocean above the spring is somewhat convex, or bulging.

Thermal springs, or hot springs, discharge water that has a higher temperature than that of ordinary springs. The water of some hot springs is ordinary ground water that has sunk to a considerable depth. As we saw, the temperature of such water rises as the depth increases. In time the heated water will return to the surface. It will make its way through upturned strata, faults, and other features that produce a natural inverted siphon. Hot springs in volcanic regions may be derived, in part at least, from so-called *juvenile water*. Juvenile water is formed as steam rising from molten rock condenses.

GEYSERS

In certain instances the water of hot springs spurts upward from the ground at intervals. Such springs are known as *geysers*. They are found mostly in three parts of the world—Iceland, New Zealand, and Yellowstone National Park, Wyoming. In most cases the eruptions take place at irregular intervals. Sometimes, however, the intervals are quite regular. Generally a series of rumblings precedes an eruption. Water begins to flow over the vent of the geyser. Then spouts of hot water shoot from the surface. These spouts may reach a height of a hundred or more meters. In some cases, however, they may be only a meter or so high.



Water trapped in a rock formation above the main water table is called a perched water body. Its upper boundary is the perched water table.

PERIODIC SPRINGS

Ebbing and flowing springs, also called *periodic springs*, differ from geysers in that their water has the temperature of ordinary ground water. During periods of flow there is a considerable discharge of water. The flow of water is sharply reduced or stops entirely during ebb periods. The interval between flows may be a few minutes, or hours, or even days. Nearly all the springs of this type issue from limestone. Modern geologists are inclined to believe that ebbing and flowing springs result from natural siphons in rock. They are quite few in number.

Before men learned how to purify flowing water and to build sanitary wells, springs furnished the cleanest and most attractive water supplies. They still serve this purpose to a limited extent in rural communities. Some manufacturers use quantities of spring water for carbonated beverages.

The curative properties of certain springs have long been celebrated. Some persons seek health by bathing in hot springs. Others drink spring water containing various minerals. Many well-known resorts have been established at the sites of these springs. Among them are Bad Ems and Baden-Baden, in Germany; Sedlcany, in Czechoslovakia; Luchon and Barèges, in France; Cheltenham, in England; Hot Springs, Arkansas, Saratoga Springs, New York, and Palm Springs, California, in the United States. There are some famous hot springs in Canada. They include the hot sulfur springs at Banff, in Alberta, and Radium Hot Springs, in British Columbia.

The waters of some springs, containing sulfates of magnesium and sodium, act as purgatives and diuretics. (A diuretic tends to promote the secretion and discharge of urine.) Mineral water derived from springs is bottled in great quantities and is widely distributed. Many people prefer it to ordinary drinking water.

GEOLOGIC CHANGES

Ground water brings about certain important changes in the earth's crust. Water charged with carbon dioxide, derived from the atmosphere, can dissolve carbonate rocks such as limestone and do-

Fritz Henle/PR

The warm water in this pool comes from thermal springs in the ground. Some people believe that such spring water has special medicinal properties. They visit spas built near these springs—like this one in Germany—to bathe in the special waters.

lomite. In humid regions great quantities of rock may be dissolved in this way and huge caverns may be formed.

Ground water often dissolves the substances that bind together the grains of the sedimentary rock called sandstone. In time it may reduce part of a sandstone formation to a heap of loose sand. The water also attacks igneous rocks, such as granite. It decomposes the iron-bearing minerals and feldspars they contain. Various minerals dissolved by ground water are transported to springs. Later these minerals are carried to rivers, and the rivers transport them to the sea. Here they frequently remain in solution, adding to the salt content of the ocean.

Often changes are brought about in underground formations by the precipitation of the materials that ground water carries in solution. When calcite, iron compounds, and silica are precipitated, they may cement together particles of sand and other loose materials. They may convert these materials into sedimentary rock. Sometimes the substances carried in solution in water are precipitated within the pores of solid rock. They greatly reduce the porosity of such rock.

Cavities formed in rock by the dissolving activity of water may be filled at some later time by precipitated mineral matter. If deposits of non-crystalline silica are laid down in this way, they later crystallize and become agate. A mineral, such as quartz or calcite, may be precipitated in a cavity in the form of crystals. If the cavity is only partly filled, the crystals will point inward toward the center of the cavity. Formations of this kind are known as *geodes*.

When ground water dissolves limestone, calcium bicarbonate is formed and is carried off by the water in solution. Later calcium carbonate is deposited, generally in the form of calcite, on the roofs, floors, and walls of caves as the water evaporates. This ultimately results in the creation of stalactites, stalagmites, fluted columns, and other structures found in caves. These deposits are called *speleothems*. They are discussed in the article "Caves" in *The New Book of Popular Science*.

In some cases ground water dissolves certain kinds of matter and replaces it with other kinds, which it is carrying in solution. This process is called *replacement*. Suppose a tree trunk lies buried below the water table. Its woody matter will gradually be dissolved away by water, and will be replaced by silica carried in solution in the water. Eventually the tree trunk will be replaced by a perfect replica in stone. The

water table may later be lowered in this area, and erosion may lay bare the tree trunk. The Petrified Forest of Arizona, in the United States, contains many fine examples of such materials. Some of the petrified logs found there are about thirty meters long.

Mineral substances carried in solution in ground water are often precipitated at or near the site of a spring as evaporation takes place. Various types of deposits are laid down in this way. They are generally very compact and hard when slow evaporation has taken place. When calcium carbonate is precipitated through rapid evaporation in hot springs, the resulting deposit has a spongelike texture. It is called *calcareous sinter.* Sometimes it forms impressive-looking mounds and terraces. Various other substances, including gypsum, limonite (an ore of iron), sulfur, and silica, are deposited by springs.

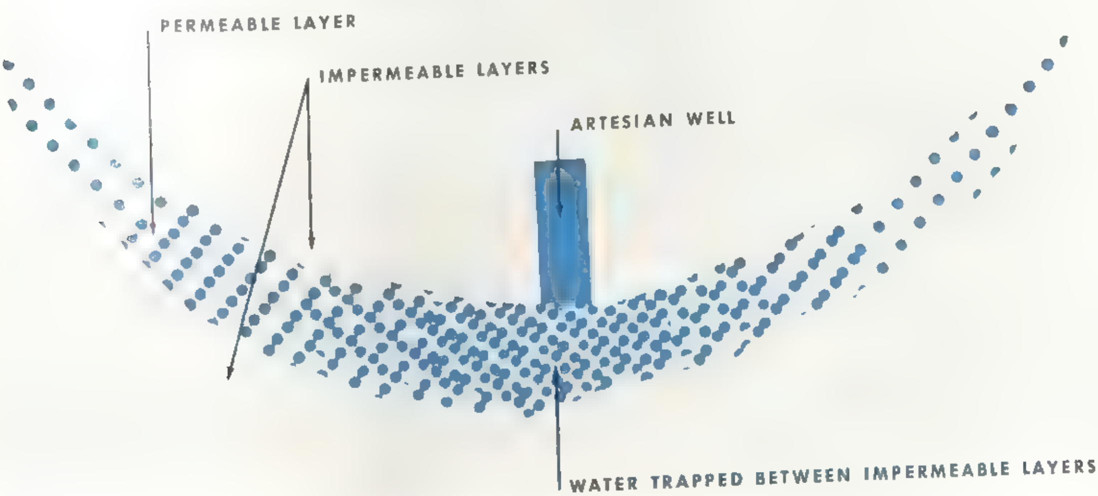
MAKING GROUND WATER AVAILABLE

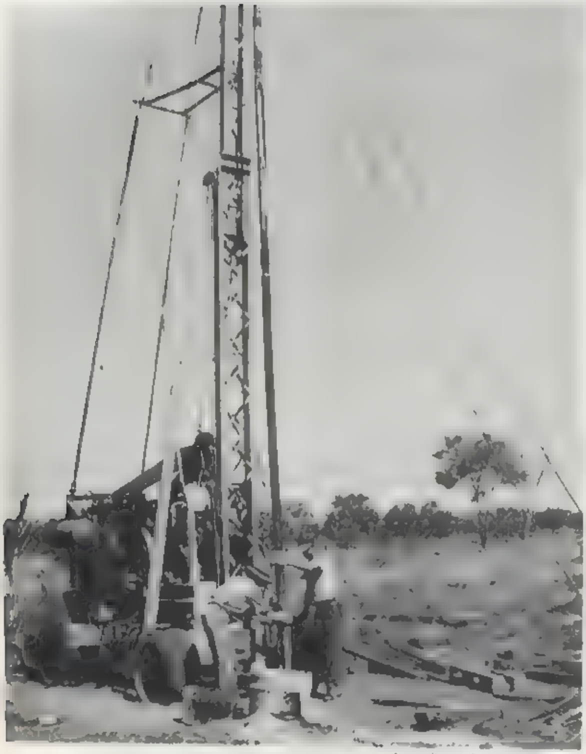
A water well is a pit or hole dug or drilled into the ground to reach a supply of water. The pit will remain empty or practically empty until it reaches the water table. If the hole is sunk into the zone of saturation, water will enter it and will come to rest at the water table. As water is pumped from the well, the water level will be lowered. However, a fresh supply of water will percolate into the hole until the level of the water table is reached again. Wells sunk in very permeable rock formations will naturally be replenished more quickly than wells in less permeable rock. If a well does not reach the water table at all times, it will become dry as the table falls. Wells range in depth from less than thirty meters to a thousand or more meters.

The construction of durable and dependable wells is an art that requires specialized knowledge and skill. It is necessary to sink the hole to the proper depth to reach a productive *aquifer,* or water-bearing formation. It is then necessary to provide proper casing for the well in order to prevent cave-ins and also to prevent pollution of the ground surface near the well.

Most domestic wells are pumped intermittently at the rate of only ten or twenty liters a minute. But many wells that furnish water for public water works, industrial plants, or irrigation yield many thousand

The name "artesian well" is given to a well drilled into a permeable bed between two impermeable layers, forming a species of natural basin.





Australian Information Service

Ground water is a source of drinking water. This source is tapped by drilling a well and pumping the water to the surface, as these Australians are doing.

liters a minute. One well on the Hawaiian island of Maui is pumped at the rate of more than 100,000 liters a minute, or almost 150,000,000 liters a day. It consists of a shaft and radiating tunnels below the water table in lava rock.

In many places a bed of clay, shale, or other relatively impermeable material overlies a permeable bed, perhaps of sand or sandstone. Under this second bed there is an impermeable or almost impermeable stratum. Suppose these alternating layers of rock form a sort of natural basin, whose surfaces slope toward a central point. There may be an outcropping of the permeable stratum at the surface some distance above the central point of the basin. In that case water will penetrate into the permeable bed. As the water descends it will be imprisoned between the two impermeable strata of rocks.

If a well is drilled at this point through the upper layer, water from the water-bearing stratum will rise in the well above the level of the stratum where it was first encountered. It may come up to the surface and overflow. A water well of this kind is known as an *artesian well*. The name is derived from Artois, a former province in France where such wells were first dug in Europe.

The digging of wells goes back to very ancient times. Primitive men, who depended chiefly on hunting and fishing, generally lived near natural watering places. Hence they progressed very little in the art of digging wells. When men began raising large flocks and herds, they faced a different problem. The pasturage within reach of natural watering places did not suffice for their livestock. Therefore, they had to provide for the needs of their animals by building wells. As the twenty-sixth chapter of Genesis shows, the Biblical patriarchs Abraham and Isaac were remarkably expert in locating and digging wells for the use of their stock.

LARGE-SCALE USE OF WELLS

Many rural communities and a considerable number of large cities obtain all or part of their water supply from wells. The largest city in the world supplied mostly from wells is Berlin, Germany. An extensive system of wells on Long Island supplements the water supply of New York City. Wells supply great quantities of water for processing and cooling purposes in industrial plants.

Wells are used extensively, too, for irrigation purposes. Millions of hectares in India are supplied with water from wells. Some of these are very ancient, with primitive devices for lifting the water. Others are of modern construction, having efficient electrically driven pumps. Wells are used extensively for irrigation in the United States. The water obtained from this source is used to irrigate fruit and other crops in California and other western states. They serve for rice irrigation in Arkansas, Louisiana, and Texas and for raising fruit and vegetables in Florida and other states of the east.

AQUIFERS

To seek out promising sources of ground water for wells, the terrain is studied by geologists. Then a series of borings are made on the basis of their observations. Deposits of sand and gravel supply most of the wells of large yields. Certain properly constructed sand-and-gravel wells may supply many thousands of liters a minute. Sandstones, derived from sand particles that have been compressed and cemented, will provide ample quantities of water if enough of the original open spaces between the grains remain. If these spaces have been filled by precipitated minerals, the sandstone may yield only moderate supplies of water from the various cracks and fissures that develop in the course of time. In some cases the sandstone may be entirely unproductive.

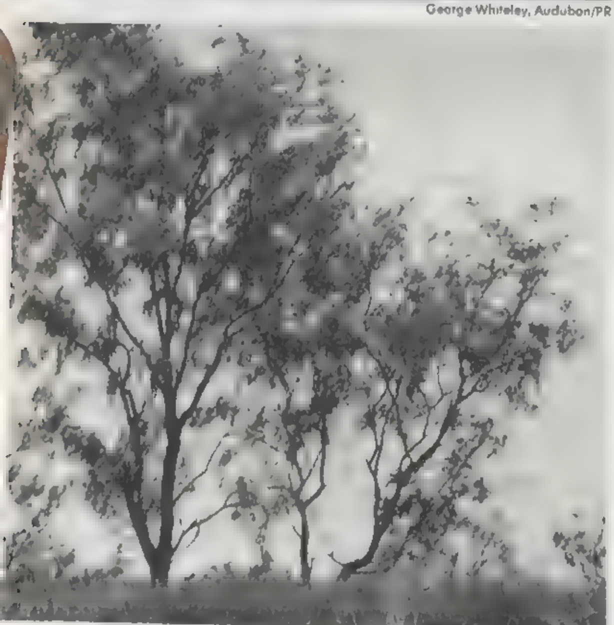
Many kinds of rocks, including granite, quartzite, and slate, are very compact and contain almost no open spaces except those formed by cracks and fissures. Some wells drilled into such rocks are entirely dry. In many cases, however, hard rocks are loosened up near the surface by various weathering processes. As a consequence, they become porous and permeable enough to yield small water supplies to wells. Certain clay formations are the most unproductive of all. They are too fine-textured to yield water and too soft to have any water-bearing cracks.

In newly formed limestone there may be abundant open spaces between the fragments of which the stone is composed.

Arabian American Oil Company

Underneath vast arid areas, such as deserts, ground water can accumulate. Where the level of the ground intersects the water table, an oasis, such as the one shown at right, may be formed

George Whiteley, Audubon/PR



Robert Lamb, Audubon/PR

Plants known as phreatophytes send down roots to ground water sources. These plants act as pumps that bring ground water to the surface. Two of the better-known of these plants are salt grass (top) and mesquite (bottom).

However, the original open spaces tend to close off or become filled. The older limestones, therefore, may be compact and impervious. In some places, however, old limestone formations have been dissolved to a great extent by percolating water. They become extremely porous and permeable. The amount of water, therefore, that one can obtain from limestone formations varies greatly. In some limestone regions, it is difficult or impossible to obtain enough water from wells for domestic and livestock needs. Elsewhere limestone may yield great quantities of water.

PLANTS THAT BRING UP GROUND WATER

Ground water is brought to the surface not only in springs and wells but also by certain plants. These put their roots down to the water table or to the moisture just above the water table. They are found particularly in places where the table is relatively near to the surface. Plants of this sort are known as *phreatophytes* (from two Greek words meaning "well plants"). In the arid regions of the world more ground water is absorbed and transpired by the phreatophytes than is discharged by springs. These plants serve to indicate the presence of underground water not far below the surface.

Among the best known of the phreatophytes are salt grass *(Distichlis)*, greasewood *(Sarcobatus vermiculatus)*, mesquite *(Prosopis)*, and various species of palms. Salt grass is widely distributed along the eastern and western coastal areas of the United States and Mexico, and along the Pacific coast of South America. It is generally confined to areas where the depth of the water table is not much over three meters.

Greasewood is found west of the Great Plains area of the United States and in southwestern Canada. The water supplies that it taps may be nine meters or more below the surface. The mesquite is a much-branched shrub or small tree, thriving in the arid regions of southwestern North America. Its big taproot sometimes reaches down 18 meters below the surface

to obtain water. Palm trees are found in the Sahara and in the Arabian deserts and in other arid areas of the world. Their presence indicates that—even in some vast deserts—there are ground water accumulations not far from the surface.

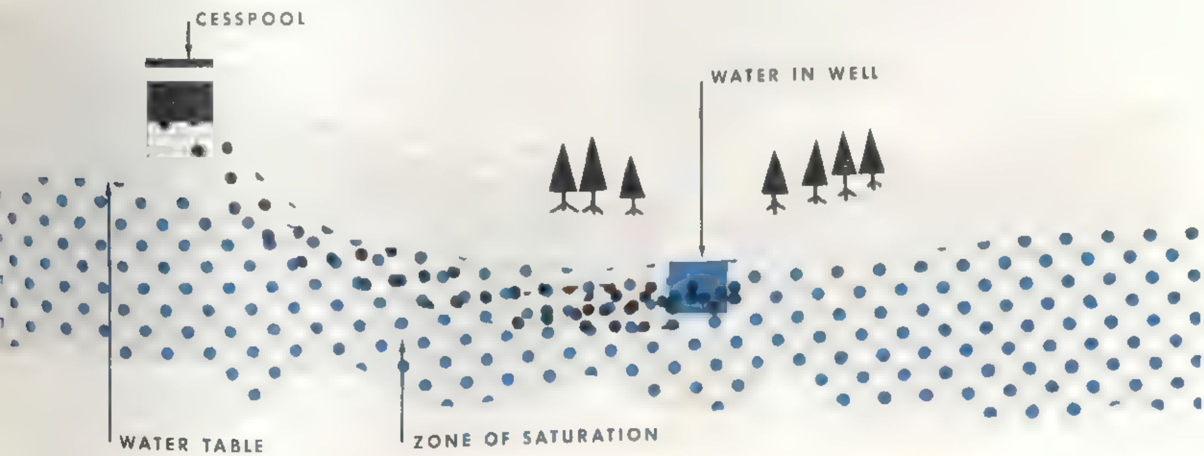
SANITATION OF GROUND WATER

When water from rain or snow runs off over the land surface it picks up particles of soil and filth. These particles contain great numbers of bacteria—some of them disease-producing bacteria. Some of this water may seep downward into the soil, reaching the water table sooner or later. The particles held in suspension in this ground water (including the bacteria) are largely removed by filtration. Any bacteria that have been disposed of in this way generally do not survive. For one thing, there will probably not be enough nutrients for them in ground water. This is particularly true if this water remains in the zone of saturation for a long time.

However, not all water supplies obtained from wells and springs are free from bacterial contamination. The water may be polluted for various reasons. It may reach the aquifer through crevices in limestone, fissures in other rocks, the open spaces in coarse gravel, or other large openings. Privies, cesspools, or the outflow of sewers may be located near the wells or springs. In addition, surface water may find its way into springs or into wells that are not tightly cased.

Wells or springs can be kept reasonably free from contamination by removing all possible sources of contamination in the vicinity. These sources are particularly dangerous if they are in an upgrade position—that is, if they occur on land higher than that in which the water source is located. In that case, pollutants may run downward into the well or spring water. It is sometimes advisable to simply abandon the old well and build a new one. This should be in an upgrade direction from sources of contamination. To combat pollution, a well should have a durable, watertight casing. It should be built far enough above the surface of the land to keep out surface water. If possible, the casing should extend downward beyond the water table to the nearest solid stratum. In any event it should go well below the water table. Wells sunk in limestone, lava rock, and other formations that may have large openings present special problems. The only sure way of protecting their water from pollution is to purify it by chlorination or some other method.

Well water may be seriously contaminated if a cesspool is in an upgrade position from it—that is, if it is located on higher land than the well.



RIVERS

The sun warms the ocean, which covers about three quarters of the earth's surface. As a result, water vapor rises from the ocean into the atmosphere, where much of it condenses to form clouds. The clouds often move over the land. If the air becomes cool enough, the moisture of the clouds falls as rain, snow, sleet, or hail.

When these forms of atmospheric water reach the ground, any number of things may happen. In a cold climate or during the winter season, the snow may accumulate for months. If the weather later becomes warm enough, the snow melts.

Much rain is absorbed by plants and soil. But excess rain runs off into low-lying areas to join or to form a stream or lake. Streams are also kept supplied by water that gradually seeps toward them under the surface of the ground.

If enough water from melted snow and ice, from rain runoff, or from underground seepage accumulates on the surface of the land, it forms small streams, or rivulets. The rivulets then run together to form streams, and the streams, rivers.

The rivers empty into the sea. The sun heats the sea, sending the water back up into the atmosphere. Clouds form, which eventually release rain or snow.

This so-called *hydrologic*, or *water, cycle* is repeated time and again, seemingly without end. Without this circulation of water, life as we know it would be virtually impossible on earth. Moreover, the movement of water across the face of the globe sculptures it into many of its most familiar features.

Mountains, for example, are changed by water action. Streams and rivers wear down rock and transport vast quantities of soil, mud, and sand. This activity is known as *erosion*. Through erosion, streams may carve a landmass into striking forms.

Although mountains are affected by the actions of streams, they in turn exert an enormous influence on the development of streams. The slope of a mountainside determines the rate at which a stream flows.

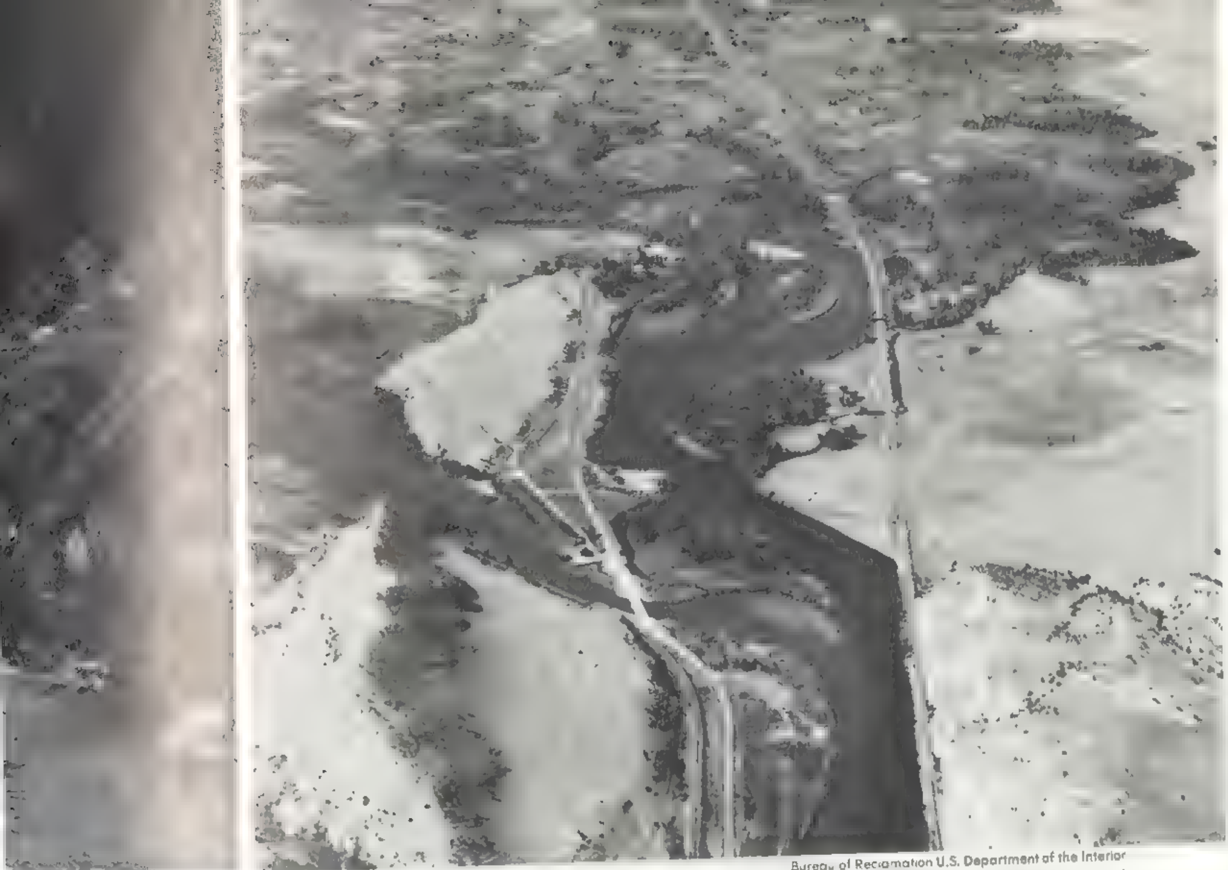
Oregon State Highway Commission

People enjoying the scenic and recreational qualities of a river. People use rivers in many ways: for recreation and transportation; as sources of water for drinking, irrigation, and industry; and to produce electric power.

Moreover, tall mountains serve as both sources and storehouses of water. Moisture-laden air is forced to rise over the peaks, where it becomes cooled. The atmospheric water then condenses into clouds and fog, which cling to the mountains. The clouds then discharge their burden of water.

Snow and ice gather on the peaks of high mountains. Deep snows fill the upper valleys during winter. But when spring comes, much of this snow melts. The resulting water rushes into streams, causing them to swell. The streams deliver their life-giving fluid to the land at the base of the mountains.

Mountains serve as natural reservoirs of water. Much of this water, of course, is frozen for part of the year. But without this condition, the water would be lost through evaporation or through absorption by a mountain's rocks and soil.



Bureau of Reclamation U.S. Department of the Interior

Three smaller rivers—the Gallatin, Madison, and Jefferson—unite to form the Missouri River at Three Forks, Montana.

WATERSHEDS

Mountains serve yet another purpose in the hydrologic cycle: they literally divide the waters. If we compare a mountain ridge to the midline of a peaked roof in a rainstorm, the meaning of this becomes clear. Water hitting the peak of the roof runs down each side. Similarly, water from mountain ridges forms streams flowing down both sides, in opposite directions. Such a ridge is called a *watershed*, or *divide*. Sometimes, "watershed" is used to indicate the whole area that contributes to a river's or lake's water supply.

The location of the great continental divides has played a momentous part in determining the economic patterns of nations involved, particularly in relation to such activities as trade and agriculture. One of the greatest and most important watersheds in the world is that in North America, known as the Great Divide. It extends from the northwestern part of Canada through the western United States and down through Mexico and Central America, and joins the Andes in South America. The great rivers that are fed by the water flowing off the eastern slope of the Great Divide run into the Atlantic Ocean or the Gulf of Mexico, and those fed by water from the western slope run into the Pacific Ocean. Much of the Great Divide coincides with ranges of the Rocky Mountains. Continental divides in other parts of the world act similarly, as watersheds. They also delimit the drainage area, or basin, of each river.

RATE OF FLOW

The actual course of a stream slopes in varying degrees. The mountain slope, or youthful stage, is steepest; the valley slope, or mature stage, is somewhat gentler; and the plain slope, or old stage, is very nearly level. A river may exhibit all three stages or only one or two of them, at any given time.

The mountain, or torrential, part of the river course slopes as much as nine or more

Bureau of Sport Fisheries ... World

Above: pollution and a spell of hot weather caused thousands of shad in Washington D.C.'s Anacostia River to die. Levels of dissolved oxygen in the river became so low that fish could not breathe. Left: a river heavily polluted with detergents and industrial wastes.

meters to the kilometer. The rate of flow may exceed 32 kilometers per hour. Even at 13 kilometers an hour a stream may displace boulders more than one meter in diameter. Much destruction and erosion are thus brought about.

The valley-stage slope may attain two meters per kilometer, giving the stream a velocity of up to 8 kilometers per hour. Sediment is transported and deposited here and there.

The plain slope represents the last stage of the river's journey from source to sea. The gradient of the bed is very slight, as the river winds its way across level plains, often of its own creation. The water flows so slowly that the stream readily drops much of the load of sediment that it is

carrying. The river is also easily deflected by obstacles, causing it to switch channels.

The carrying power of running water increases tremendously with increase in its speed of flow. If the velocity becomes a few times greater, the transporting power may be increased several hundred times. However, speed of flow is not the only factor governing the ability of a stream to move debris. The type of flow and the shape of the bed and of the sedimentary particles are also important. A stream's velocity is usually great in its mountain and valley stages. Even at two to three kilometers an hour, a river may move cobble-size stones and pebbles. At about one kilometer per hour, gravel is swept along. But if the velocity is much slower than that, a river may not even disturb fine sand or clay.

At very low speeds, a stream will drop much of its sediments, thus building up its bed. This is particularly true of rivers in the plain stage, or old age. They thus construct wide stretches of so-called *alluvial plains*. During floods, the river deposits fertile mud alongside its course. Civilizations have arisen on such flood plains, such as those of the Nile in Egypt, the Tigris and Euphrates in Iraq, the Indus in India, and the Yellow River in China.

The rate of flow of an old river is very easily modified by irregularities or obstructions in the river bed. When the river is slowed up in any way, it deposits part of its load at that point. This causes it to swerve toward the opposite bank, which it will tend to scoop out. The water will then be deflected by this concave section of the bank to the opposite bank, which will be hollowed out in its turn. One curve will lead necessarily to another similar to it. The Mississippi River forms a series of curves.

As a young river cascades over a slope, a waterfall is formed.

Philip Gendreau, N.Y.


Photo Researchers

Glacial streams, such as the one pictured at right, are swelled by melting snow and ice during warm-weather periods, and often run together to form rivers.

The larger the stream, the longer the curves it describes. A brook may gouge out several in a single field. A large river, on the contrary, may form a single curve of 15 to 30 kilometers and return almost to the place where it started. These curves are called *meanders*. The name is derived from that of the River Maeander, in Asia Minor, a river about 400 kilometers long and now known as the Menderes, in western Turkey, along which many meandering curves are to be found.

MEANDERS LENGTHEN THE COURSE

In most cases meanders occur in the lower, broadened parts of river valleys, where the gradient or slope downward is not very great. The result of the winding or meandering of rivers is to extend greatly their courses from source to sea. The Scottish Devon meanders for 42 kilometers, to cover a straight-line distance that is only 10.5 kilometers. The Nile extends its journey by some 800 kilometers. Meanders reduce the gradients of rivers, much as long, winding loops reduce the gradient of a road down a mountain, and make them easier to navigate. They often also increase the importance and efficiency of rivers as means of drainage and irrigation.

The Black River, in northern New York, meanders through the wooded countryside. Meanders usually occur in the lower parts of river valleys.

After it has made a loop, a river may turn back again and cross the loop, forming an island. In some cases the short cut across the loop becomes part of the main channel of the river and the entrances to the loop are cut off by the deposit of sediment. In this way are formed the strange crescent-shaped bodies of water—cut-off loops—that are known as *oxbow* lakes. In the basins of the Mississippi, the Ganges, the Rhone, and the Po there are many of these lakes. More than once, by such cutoffs, the Mississippi has shortened its course by about 50 kilometers and has even left many kilometers away towns that once were on the river banks.

FLUCTUATIONS IN VOLUME

Sometimes a stream or river is "full," carrying a heavy load of water that fills the channel from bank to bank. At other times it may be reduced to a mere trickle or even dry up altogether. Heavy rainfalls and melting snow near the source increase the water volume, while long periods of drought and insufficient snowfall reduce it correspondingly. Often these fluctuations, which may be extreme, are very sudden. A mountain stream, which may be, in ordinary times, only a runlet, will on the occasion of the first thaw be quickly changed into a river running almost 50 kilometers an hour, overflowing its banks. In some tropical valleys, the amount of water in the streams fluctuates greatly with the daily heavy storms. In other regions in the tropics, many rivers of medium size are often dry for half the year. In the country around the Red Sea, for instance, there is a perfect system of river beds, but they hold water only during the rainy season.

By the *discharge* of a river, we mean the amount of water that flows past any given cross section of the river channel in a given period of time. It is expressed in the number of cubic meters per second.

FORMATION OF DELTAS

At Natchez, Mississippi, the average discharge of the Mississippi River is between 16,200 and 18,900 cubic meters per second, although it may drop to below 2,700 cubic meters a second or rise to more than 54,000 cubic meters. To understand what such large rates of flow mean practically we must realize that a discharge of one cubic centimeter per second amounts in one day to about 90 liters. The Amazon River, in South America, in many ways the world's greatest river, has a discharge so great that the river water, with its load of silt, is visible to observers in the Atlantic Ocean, 320 kilometers from land. It is not only the amount of precipitation and runoff that affects the amount of discharge, but also the configuration of the channel and the roughness of the stream bed.

As a large river flows along, it usually picks up and carries with it various kinds of debris—branches of trees, sticks, stones, and even soil itself, which it carries as sediment. When the river water is discharged into a still body of water, such as a lake or even the ocean, the sediment is dropped to the lake or ocean floor. Gradually, this sediment forms a triangular-shaped fill at the mouth of the river. This built-up area, which constantly grows outward, into the lake or the ocean, is called a *delta*, after the Greek letter with the triangular form. Delta sizes and shapes vary widely. When a big river runs clear, carrying little or no sediment, no delta, obviously, can be formed. The Niagara River, for instance, carries little sediment along with it, so there is not enough silt to build up a delta at its entrance into Lake Ontario. In many cases, deltas eventually become more or less solid land and sometimes cities are built on them. The deltas of the Rhine, the Maas, and the Scheldt rivers in time became, in large part, the land that we now know as the Netherlands. Among the great deltas of the world are those of the Mississippi, the Nile, the

Melting snow may feed mountain lakes that, in turn, feed swift-moving rivers. These rivers carry much sediment—from eroded banks and beds—downstream. Even large objects, such as logs, may be transported.

f Colorado

Amazon, the Po, the Tiber, the Danube, and the Ganges.

The countries of the world, except those in desert regions, are crisscrossed by waterways, from very small and insignificant creeks to the broad, long water highways on which so much of the world's commerce is carried. Before the days of super highways and air traffic, the rivers transported many more passengers and goods than they do at the present time. Rivers and lakes have also always been the main source of water supply. About three-quarters of the cities in the United States today use water from these sources. Because the rivers have always furnished ready-made water roads and water power, people have been inclined to build settlements, industries, and modern cities on the very banks of the rivers. In doing this, they have frequently taken a calculated risk because, when the force of the waters turns against man, it is a destructive power equal to that of rampaging fire or wind.

FLOODS

From the earliest times, floods have taken a terrible toll, not only in property destruction but in human life as well. The Hwang Ho, or Yellow River, of China, the second largest river in that country, is often called "China's Sorrow" because of its large record of devastation. Again and again it has changed its course and during the centuries its floods have taken millions of lives. The most celebrated floods in the world are probably the periodic floodings of the Nile in August and September. The Nile's flood waters, with their burden of fine, fertile soil, irrigate and fertilize the flood plains of Egypt. The river, which was once believed to have its source in the "Mountains of the Moon," a group of mountains in east-central Africa, is now known to originate in the mountainous regions of Ethiopia. Efforts to control the flood waters of the Nile began as much as 6,000 years ago, and today diversion dams

Grinnell Lake in Montana's Glacier National Park. The lake formed by mountain streams provides habitats for many animals, including fish and beavers

Montana Dept. of Highways

Unfortunately, rivers are destructive as well as beneficial. Here flo[illegible]s have washed out valuable topsoil and ruined farm property.

and reservoirs have largely tamed the great river.

The United States has floods of such rivers as the Mississippi, the Missouri, the Ohio, and the Connecticut, as well as others. In bad years these floods drive thousands of people from their homes and cost many lives. In the United States alone, the flooding of rivers destroys more than a thousand million dollars' worth of property, on an average, each year, despite the huge flood-control programs that have been initiated. Engineers have learned that floods can be prevented by the building of diversion floodways, dams, and reservoirs to carry off and store excess water. On the Mississippi River increasingly effective levees have been built and channels are altered at danger points by dredging and cutoffs.

FLOOD CONTROL

The new philosophy of flood control holds that flood prevention should begin near the headwaters of the rivers, and not when the floods are already out of control down in the flood plains and near the river deltas. By the proper management of farm, ranch, and forest lands in the watershed near the river's source, much of the excess water from the sudden melting of snow in mountains and from heavy thunderstorms and torrential rains can be induced to run back into the ground where it will be available as subsurface water when it is needed. Engineers advocate the use of small storage reservoirs from which the waters can be released when there is an inadequate supply in the rivers. In this way, the water is not just allowed to overflow the river banks and waste itself, at the same time doing an incalculable amount of damage. Flood-control programs are inextricably linked with proper conservation practices.

RIVER COLOR VARIES

Rivers vary in color and sometimes are named according to their apparent color. There are many "white" rivers. One stretch of the Nile is known as the White Nile and in Spanish-speaking countries there are many rivers called "Río Blanco" (White River). Another part of the Nile is known as the Blue Nile. There is a Red River in the United States and the Yellow River in China. In some cases the color of a river is due to the color of its bed or of its reflected banks. Thus, the Black River of Kenya and

Tanzania appears black because of the black lava over which the water flows. In other cases it is the contents of the river, such as clay or peat, that give the characteristic color. The water from different rivers varies also in taste, according to the mineral ingredient

SOME VERY LONG

When we consider the rivers of the world, we begin to realize that it is not always the longest ones that are most useful to man. They may not be navigable or they may flow through largely uninhabited regions. On the other hand, such comparatively short rivers, measured in kilometers, as the Thames (345), the Seine (775), the Rhine (1,320), the Hudson (490), the Connecticut (6[illegible]), and the Ottawa (1,100) have made invaluable contributions to the advance of civilization.

In many cases it is almost impossible to consider a great river by itself, when it is part of an enormous system of water courses. The Mississippi River proper, for instance, is about 3,750 kilometers long, but the Mississippi-Missouri system extends for more than 6,480 kilometers.

Of all the continents, South America has the most impressive display of great rivers—the Amazon, the Paraná, and the Orinoco. Some of the tributaries of the Amazon and the Paraná are themselves huge rivers. The three giant waterways communicate by tributaries and there is an almost continuous network of water from the north of the continent to the south. The Paraná joins the Paraguay to form the estuary known as the Río de la Plata.

As the great rivers of the world flow along through the countryside, they drain enormous areas of land. The drainage basins of some of the largest rivers are as follows in square kilometers: the Amazon, 5,277,000; the Congo, 3,444,000; the Mississippi-Missouri, 3,184,000; the Río de la Plata, 3,079,000; the Nile, 2,878,000; the Yenisei, 2,668,000; the Ob, 2,400,000; the Lena, 2,395,000; the Amur, 1,822,000; the Mackenzie-Peace, 1,797,000; the Yangtse, 1,771,000; and the St. Lawrence, 1,452,000.

TWENTY-FIVE GREAT RIVERS OF THE WORLD

River	Continent	Outflow	Length (kilometers)
Amazon	S. Amer.	Atlantic Ocean	6,280
Amur	Asia	Tatar Strait	4,350
Congo	Africa	Atlantic Ocean	4,370
Danube	Europe	Black Sea	2,780
Ganges	Asia	Bay of Bengal	2,510
Hwang Ho	Asia	Yellow Sea	4,350
Indus	Asia	Arabian Sea	3,060
Lena	Asia	Laptev Sea	4,260
Mackenzie-Peace	N. Amer	Beaufort Sea	4,050
Madeira	S Amer	Amazon River	3,380
Mekong	Asia	S China Sea	4,180
Mississippi	N Amer	Gulf of Mexico	3,750
Murray-Darling	Australia	L Alexandrina	3,720
Niger	Africa	Gulf of Guinea	4,180
Nile	Africa	Mediterranean	6,670
Ob	Asia	Gulf of Ob	4,020
Orinoco	S. Amer.	Atlantic Ocean	2,740
Paraguay	S. Amer	La Plata River	2,400
Parana	S Amer.	La Plata River	3,300
Rio Grande	N. Amer	Gulf of Mexico	3,030
St Lawrence	N Amer	Gulf of St Lawrence	3,130
Volga	Europe	Caspian Sea	3,690
Yangtse	Asia	E China Sea	4,990
Yenisei	Asia	Kara Sea	3,800
Yukon	N. Amer.	Bering Sea	3,180

GLACIERS

by Richard P. Goldthwait

The masses of ice that we call glaciers cover about a tenth of the earth's land surface. The great ice sheets of Antarctica and Greenland account for most of this area, but there are also thousands of smaller ribbonlike formations in lofty mountains. Glaciers are not inert features of the landscape. They are constantly creeping, spreading, and retreating.

In past ages they expanded greatly over the land. Four times in the Pleistocene epoch, extending roughly from 1,000,000 years ago to 8,000 B.C., thick, moving ice sheets covered large parts of North America, Europe, and Asia. The icecaps of Antarctica and Greenland represent comparatively small remnants of two of the vast formations that covered almost a third of the land in the last ice age.

It is fortunate for us that glaciers have now dwindled in size. For one thing, this means that people have greater living space and can enjoy a warmer climate. Besides, as glaciers have disappeared from much of the land, they have left behind valuable evidence showing just what a great ice mass does to the land under it. The moving and grinding ice sheets of past ages swept the rock bare of soil, polished and engraved ledges of "fresh" rock, diverted old rivers, and then left the old valleys covered with new soil. By making a careful study of the evidence left by old glaciers, as well as by exploring modern ones, geologists have learned a great deal about what these ice formations are and what they do.

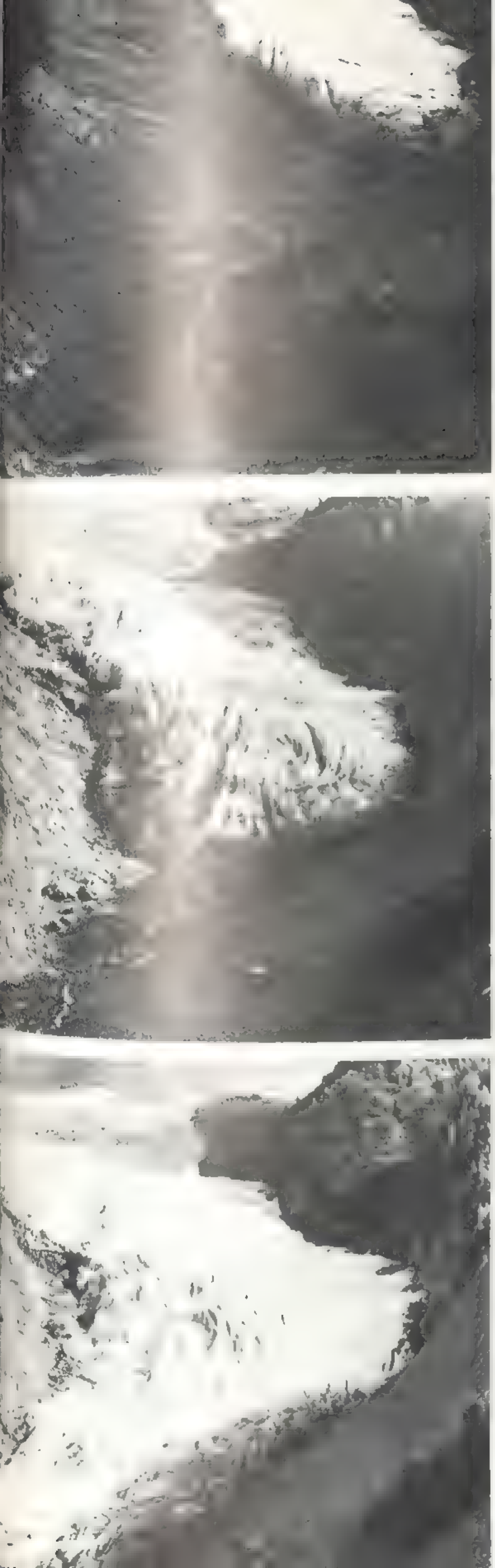
FORMATION OF A GLACIER

Glaciers form because in various high mountains and plateaus some of the snow that falls each winter fails to melt during the next summer. This happens in places where the average temperature in the summer months is near or below freezing. New snow falls on top of the residue from the previous year and vast snow fields are formed. The total snow cover becomes thicker, year by year, until the lower layers are transformed into ice. This is the *area of accumulation*.

When the snow field in the area of accumulation has reached a certain critical thickness (approximately 60 meters), a huge mass of ice and snow begins to move downhill or to spread outward. A glacier has been formed. Its forward progress will continue as long as enough snow accumulates on the snow field from which it is derived. At last its spreading edge will reach a place where the temperatures in summer average well above the freezing point —0° Celsius. In this area all of the past winter's snowfall will melt or evaporate during the summer. Some of the creeping ice beneath it will also melt, so that the ice mass becomes thinner and thinner as it flows. This is the *area of dissipation*. A glacier can maintain itself in a given place only as long as the supply of ice from colder areas equals the total of melting and evaporation.

How is snow transformed into the ice of a glacier? Fresh snowflakes seen through a lens are beautiful lacy six-pointed crystals. In mountain areas, driving clouds add light "frost feathers" made of platelike crystals of ice. The crystals pile up deeper and deeper, especially in valley basins where drifts may gather six meters deep in a single storm. The weight of a few meters of snow forces the sharp points of the flakes together and the melting point is lowered a little by pressure. Melting particles break off and instantly refreeze in the open spaces between the the flake centers. Near snow line—the lowest limit of perpetual snow—air or rain may penetrate these spaces during the warmer part of the day, and other parts of the flakes are melted. The evaporation of solid ice through sublimation brings changes in the structure of flakes even in very cold weather. Little by little the six-sided flakes become pellets of ice.

Where there is great pressure, the pellets are squeezed together like so many grains of pasty tapioca. The product is *firn*, which is a half-formed ice. Firn is milky white or gray in color because of the many trapped air bubbles. As these air pockets are squeezed out, the firn is transformed



into granular ice. The grains of ice are no bigger than BB shot. They fit against one another as closely as the interlocked pieces of a jigsaw puzzle. As the whole ice mass makes its way outward and downward the grains become larger. Small grains become parts of larger ones. In the area where the glacier ends, the ice granules may be as big as marbles or even egg-sized.

FLOW OF A GLACIER

The flow of a glacier is rather complicated. Deep down, where the pressure of the overlying snow and firn is tremendous, the ice actually flows downhill. Any solid, even the hardest metal, can be made to flow if enough pressure is applied to it. When the slowly moving ice reaches a curve in the valley, it flows around the curve. Near the end or edges of the glacier, the ice may break internally as though cut by a saw, so that one large portion will shear over another portion. Under strain, portions of small granules may change the internal arrangement of their molecules. These molecules are realigned so as to become part of the adjacent large granules, and this shift contributes to the motion of the glacier. In one way or another the glacier moves along very slowly from its source to warmer surroundings.

TWO TYPES OF GLACIERS

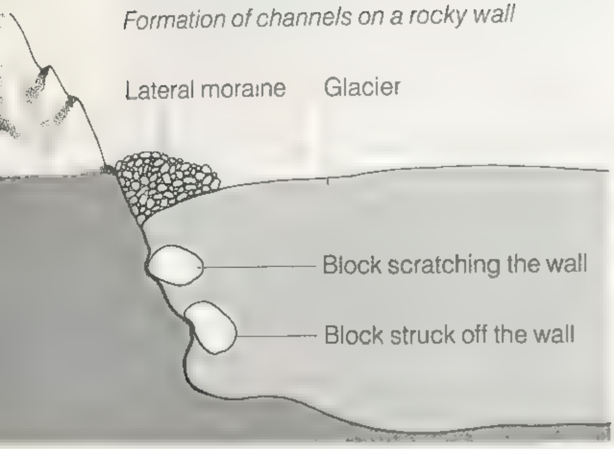
Glaciers can be divided into two principal types: mountain and continental.

Mountain glaciers are also called *valley glaciers* and *alpine glaciers* (after typical examples in the Alps). They generally cover only a few square kilometers or a few tens of square kilometers. Mountain glaciers are formed when snow falls on high slopes, and then avalanches or blows into valleys. Here the accumulating mass turns to firn and ice and oozes slowly down the valley. The glacier is restricted in its flow, of course, by the walls of the valley. Certain mountain glaciers emerge from their valleys and spread out over plains. These

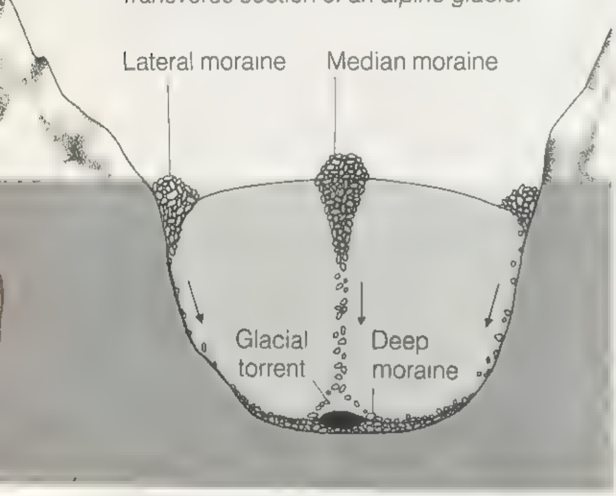
The evolution of a glacier. During a six-year period, this glacier in the Alps has enlarged and flowed down a valley.
Bouverot, Direction departamentale de l'agriculture, Annecy, France

Glacial erosion

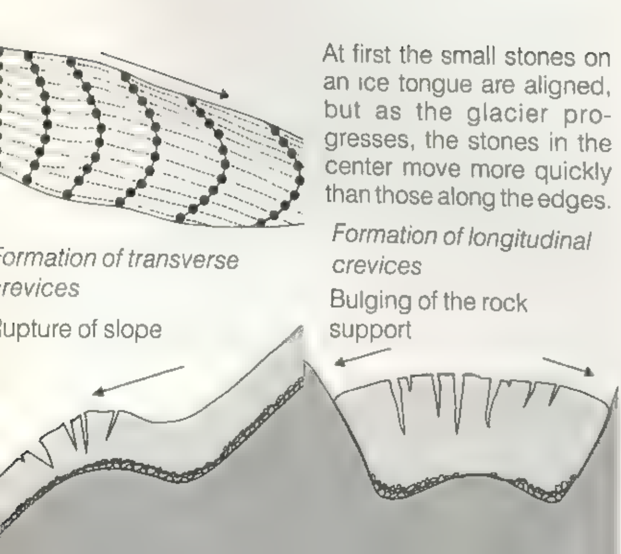
Formation of channels on a rocky wall



Transverse section of an alpine glacier



Glacial movements



are called *piedmont glaciers*–that is, glaciers that form or lie at the foot of mountains. *Pied* means "foot" in French: *mont* means "mountain.

Mountain glaciers are found in many parts of the world. In North America they are distributed along the mountain ranges of the Pacific Coast from central California northward. Mountain glaciers abound in the Andes range, in South America. They are familiar and greatly admired spectacles in the Alps, the Pyrenees, the Caucasus Mountains, and the mountains of Scandinavia. Rivers of ice flow down the valleys of various Asian mountain ranges, including the Himalayas, the Hindu Kush, and the Karakoram and Kunlun ranges. They are a feature of the Southern Alps of New Zealand and are found in the lofty mountains of New Guinea. The largest piedmont glaciers are the Malaspina and Bering glaciers, both in Alaska.

Continental glaciers, the second type, are also known as *ice sheets* and *icecaps.* There are only two major ice sheets at the present time. One of them covers most of Antarctica and has an area of some 12,500,000 square kilometers. The other, extending over most of Greenland, is about 1,800,000 square kilometers in area. There are smaller icecaps in Scandinavia, Baffin Island, Iceland, northeastern Canada, and elsewhere. As we pointed out, continental glaciers that have now disappeared once covered vast regions of North America, Europe, and Asia.

Ice sheets are spread out like enormous pancakes upon the "griddle" of the earth. The snow that feeds them gathers most deeply somewhere near the central part of the ice mass. The ice slowly flows outward in all directions. Sometimes the ice "batter," which may be more than a kilometer thick, completely buries mountains. In some places only mountain tops protrude above the crawling mass.

Both mountain and continental glaciers have a very important effect upon the level of the sea. The ice contained in them has been built up from moisture in the atmosphere–moisture that has been precipitated chiefly in the form of snow. All moisture

of this kind is derived ultimately from the ocean. Obviously the more moisture there is locked up in the ice and snow of glaciers, the less water there will be in the sea and the lower the water level.

It is estimated that during the last ice age the level of the sea was something like 75 meters lower than it is now. If all the ice and snow contained in the glaciers existing today were to melt away, the present sea level would be raised about 45 meters. Vast areas of what is now dry land would then be under water.

MOUNTAIN GLACIERS

Most mountains receive more rain or snow than the nearby lowlands. The reason is that as wind is forced up over the mountains, it is cooled. Cool air can hold less water vapor than warm air. Therefore some of the moisture that had evaporated over warm oceans is forced to condense over mountains as visible clouds. Precipitation then takes place, in the form of snow (or rain). Some mountains, such as Mount Ranier in the United States and the Alps, are located right in the path of moisture-laden winds from the ocean. Here snowfall is heavy and glaciers are well fed. Where winds carry comparatively less moisture, snowfall is correspondingly light and glaciers are comparatively insignificant.

The constant winds of high mountains cause snow to drift across peaks into broad basins or valleys. Snow that drives onto steep slopes cakes heavily. In the heat of midday it may suddenly break loose as an avalanche and roar down into the nearest valley with the noise of a dozen thunderstorms and a billowing cloud of snow. In other areas big chunks of snow roll down to the valley below. In one way or another snow gathers near the head, or topmost part, of the main valley. This becomes the area of accumulation.

When the mass of firn and snow in this area has reached the critical depth, the glacier begins to flow away from the head wall, down the slope. As the ice retreats, a huge crevasse, or deep crevice, known as a *bergschrund*, forms at the head of the glacier. When winter comes, the bergschrund is filled with snow and debris. Toward the next summer it opens again. While it is open, the sides and floor of the rock basin are exposed to the erosion of falling debris and weathering. Melt water forming in this area makes its way into cracks in the surrounding rock wall. At night the water freezes and the resulting pressure splits out solid blocks of rock. This process is known as *frost wedging*. The glacier itself exerts a most powerful force on the head wall. Between the ice and the rock to which it has frozen a tremendous force of adhesion exists, about equal to the cohesive strength of the ice itself and amounting to nearly 70,000 kilograms per square meter of surface. When the glacier begins to pull away from the head wall, gigantic blocks are torn loose and carried away, particularly if they are faulty or weakly jointed. This process is known as *glacier plucking*. Block by block the head wall and rock floor are quarried, undermined, and eroded.

CIRQUES AND HORNS

As this erosion continues, a natural amphitheater is formed; this is called a *cirque*—from a French word meaning "circle" or "ring." The average cirque is about 300 meters deep and measures more than one and one half kilometers across its cliff-walled top. In some areas, as in the southern Rockies, snow and ice have completely disappeared from cirques formed long ago.

The cirques on opposite sides of a mountain summit encroach upon the crest that divides them, as their walls are undermined by plucking and frost wedging. In time the crest is reduced to a knife-edge ridge, called an *arête*. Other ridges are sharpened between cirques on the same side of the summit. In time there develops a main ridge with smaller ones branching off from it.

As two cirques work their way back into the divide that separates them, they may ultimately gnaw their way right through it, leaving a large gap. That is how many mountain passes have been formed. In other cases, three or more cirques may cut back into the same mountain peak, ap-

proaching from different directions. Ultimately the peak will be carved into a spire, called a *horn*. Each horn has several facets, formed by different cirques. There are many striking examples of horns: among the most famous are the Matterhorn, Wetterhorn, and Aletschhorn, in the Alps.

VALLEY EROSION

As glaciers flow down from the cirque, they erode the valleys that hem them in. Valley erosion takes various forms. Rock fragments embedded in the ice are dragged along the rock floor of the valleys. In some cases irregular blocks of rock on the valley floor are transformed by constant friction into polished, streamlined knobs, as much as 30 meters long. Parallel scratches, called *glacial striae*, are formed on both the rock floor and walls as sharp rock fragments pass along them. It is almost as if the striae had been gouged out by the teeth of a gigantic comb dragged down the valley.

Cracks develop on some parts of the rock floor. Whole blocks of rock are then plucked out as they freeze to the glacier. Especially pronounced deepening of this kind almost always produces rock basins that hold little lakes after the ice has disappeared. Sapping of the rock walls of the valley occurs through the freezing of melt water in cracks in the rock.

So the valley broadens and its walls are kept steep. In time it develops a U-shaped cross section. A mountain that has been subjected to the carving activity of glaciers generally shows a number of deep U-shaped valleys winding outward from the cirque and opening onto the lowland areas that surround the mountain.

Mountain glaciers do not move at a uniform rate down their valleys. Measurements begun more than a hundred years ago in the Alps and recent more precise measurements show that the rate of motion varies from hour to hour, from month to month, and from place to place. The surface of South Crillon Glacier, in Alaska, was found to advance in tiny jerky movements. It would edge forward about one half of a centimeter in one fifteen-minute period and would not move at all during the next such period. Irregular movements of this sort may be due to alternating strain and sudden release in the surface ice. Day-to-day motion seems regular and constant by comparison. Yet some glaciers move even less than a centimeter a day, while others move 15 meters or so. Black Rapids Glacier, in Alaska, once "galloped along" for a time at the rate of 30 meters a day.

The center of the glacier moves faster than the sides. In the nineteenth century rows of stakes were set out straight across the Rhone Glacier. After two years the stakes formed a gentle convex curve. Eight years later, the curve was so deep that it suggested a horseshoe. The top of a glacier moves faster than the bottom.

The surface of a valley glacier is a fascinating place. In some areas it is as smooth as a billiard table. In others it is crisscrossed with crevasses and studded with needlelike peaks of ice that may reach a height of nine meters. Crevasses and peaks are found in places where the bottom ice of the glacier flows over irregular portions of the valley floor, causing the surface layers to be broken up. Once the glacier has passed these uneven places, continued melting reduces the ice peaks and some cracks squeeze shut. In the area of accumulation above snow line, cracks may open and close underneath a bridge of winter snow. Such a bridge is treacherous.

MORAINES

Rocks and dirt accumulate on the melting surface in the zone of dissipation. Usually this debris is concentrated in longitudinal bands, or *moraines*. The word "moraine" refers to several kinds of accumulations forming on a glacier or deposited by it. The rocks falling onto the glacier from cliffs along its sides and the rock fragments scraped from the valley walls form *lateral moraines*—one at each side of the glacier. Where two glaciers join like the branches of a river, a lateral moraine of one branch merges with a lateral moraine of the other. Since this combined band is now well out in the middle of the enlarged glacier, it becomes what is known as the *medial moraine*.

Alain Percival

As two large glaciers join, a large medial moraine, or band of debris carried and deposited by a glacier, is formed.

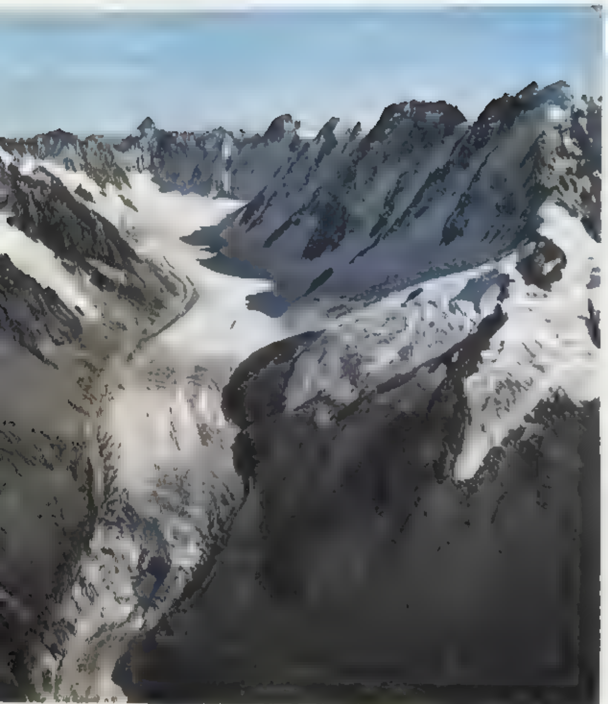
Big rocks and thick patches of dirt in these moraines rest upon pedestals or cones of ice. The reason is that while the ice that surrounds the rocks or dirt patches melts several centimeters each summer day, the ice underneath them is protected. Isolated small dark pebbles may absorb extra heat, since dark objects absorb heat, while light-colored ones reflect it. These dark pebbles melt their way into little pits in the ice.

In many areas a glacier flowing in a tributary valley merges with the larger glacier flowing down the main valley. The relatively thin glacier in the tributary cannot gouge out its valley as deeply as the main glacier. After both have melted, the tributary valley is left dangling above the main valley, forming what is known as a *hanging valley*. It is believed that the hanging valleys of the Finger Lakes region, in New York State, were formed by glacial action.

As the glacier approaches its terminus, it becomes thinner and thinner. For example, South Crillon Glacier, in Alaska, is about 370 meters thick at snow line. It is

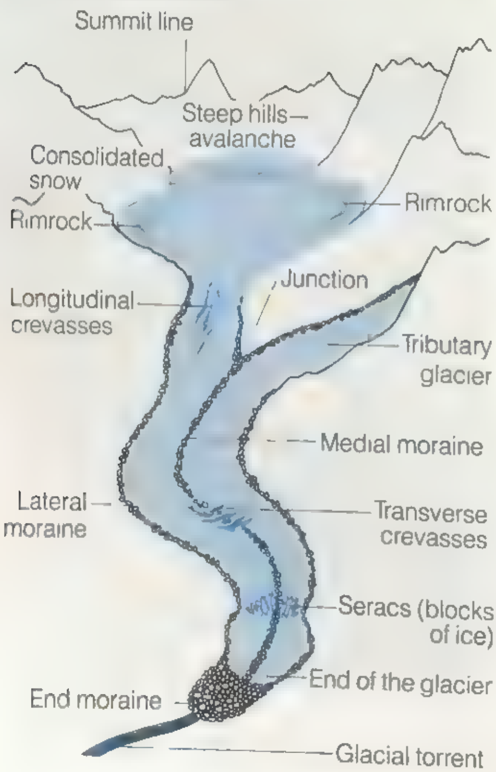
Jacana

In spring, warmer temperatures may cause pieces to break away from a main glacial formation.



Alain Perceval

GENERAL STRUCTURE OF AN ALPINE GLACIER



only 100 meters or so thick at its terminal cliff, five kilometers down-valley. It thins at the rate of almost seven meters a year while it moves 100 or 125 meters. As the glacier dwindles away, all the rock fragments in the upper layers are concentrated on the surface. The terminal part of many glaciers is completely covered with this *ablation*—carried-away—*moraine*, which may be thick enough to support vegetation.

If the terminal portion of a glacier remains in one place for a few decades, the surface debris is dumped in hummocks or ridges at the ice edge. These stretch in a great loop down the valley from one side to the other. Long after the glacier has melted away, this *terminal moraine*, as it is called, marks the site of the ice edge. The Rocky Mountains are full of these looped moraines.

Mountain glaciers have produced the great fiords of the coasts of Norway, Alaska, southern Chile, and New Zealand. Enormously deep U-shaped troughs, produced by glacial erosion, have been flooded by the sea. Their cliff walls form the rugged shores of ribbonlike bays from 10 to 60 kilometers long. Some fiords are more than 1,200 meters deep. In certain instances rivers began the work of sculpture that produced the fiords—they eroded their way through soft rock formations. Later, when the climate became colder, the glaciers took over.

CONTINENTAL GLACIERS

The snow that feeds continental glaciers falls all year round at about two or three kilometers above sea level. Much of it results from sweeping snowstorms, in regions where cool air from the polar regions meets warmer air from the sea. Some of the winds are due to a so-called *glacial anticyclone*. Air cooled on the snow surface becomes compact and dense. Since the surface of the continental glacier is curved gently, like the top of a huge watch crystal, the heavy air tends to make its way down the gentle slope, and outward blowing winds arise.

Left above: a typical alpine glacier. Below: art showing the major parts of such a glacier

Lenars

A continental glacier, or ice sheet, covers most of Greenland. The photo above shows chunks of ice floating near the coast of Greenland.

The ice flows most rapidly deep down in an ice sheet. This has been shown by the powerful valley-eroding action that has created mountain lake basins a hundred or more meters deep. It has been estimated that the ice velocity increases with ice surface slope and that the erosion power increases with the square of the depth.

Snow does not collect at a uniform depth all over the ice sheet from century to century. As unusually heavy snow deposits are built up in one area, of perhaps a few thousand square kilometers, ice squeezes out more rapidly from under that area toward the margin of the ice sheet than in other parts of the sheet.

The top of an icecap is about the flattest plain you ever saw, in spite of its watch-crystal shape. The slopes down toward the ice edge can hardly be detected. The skyline is flat, except for an occasional protruding mountain top, and on gray days it merges with the sky. In the interior about the only relief in the monotonous scenery is provided by long windblown ridges of snow, called *sastrugi*.

However, within a region of about forty kilometers from the edge of the ice, the slope is steeper and the increasing speed of the bottom ice tears the rigid firn into great parallel crevasses. Each crack is up to two kilometers or so in length and a few meters wide at the top. Where the ice sheet is banked up against mountains at its outer edge, it squeezes tongues of ice that look like valley glaciers through the mountains. In some places, ice feeds into valleys, far below the surface of the ice sheet. A broad dimple a few kilometers across the surface marks the place where the ice is pouring out rapidly below.

Continental glaciers bring about great changes in the surface appearance of the earth in a few thousand years. To have a good idea of how these transformations take place, we have but to examine the landscapes of the northern parts of North America, Europe, and Asia, which were molded by the enormous continental glaciers of the Pleistocene epoch.

SURFACE CHANGES

Where hills and mountains were encountered, as in New England and New

York, the ice often moved right over the highest peaks. We know this is so because rocks of distinctly foreign types, originating in valleys several kilometers away and as much as 1,200 meters lower down, are found at the tops of high peaks, such as Mount Washington in New Hampshire. These mountains were sanded off and rounded by the dragging debris.

At the same time the rock fragments transported by the ice engraved sets of long striae. Where many stones channeled through a weak area, glacial grooves from a few centimeters to a meter or so broad were formed. Tough rock surfaces took a fine polish from the silts and clays rubbed over them. The striae and the polished surfaces have been preserved only if glacier deposits protected them from weathering during the many years that have elapsed since the last ice age.

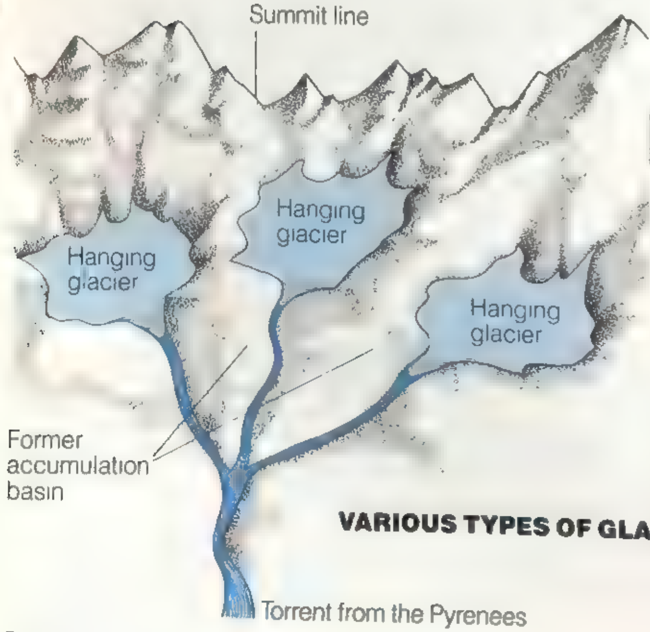
Small, hard nodules in rock formations were not ground down as far as the rest of the rock, as the ice mass passed over them. Not only did they withstand the effects of the creeping ice, they also protected the soft rock adjacent to them from the abrasion of creeping stones. The surviving soft-rock section looks somewhat like a c et, with head and flowing tail. This "cra nd-tail" formation shows us which wa he ice moved.

On the lee side of each hi he side away from the approaching gla —loosened blocks, large or small, we lucked out. Existing rock structures s est that here glacial excavation was m deeper than elsewhere—perhaps 30 ters of solid rock was removed in many es. For this reason cliffs predominate the lee slopes of hills in glaciated coun Where this shaping of hills went on lo nough, the final result was an oval rock shaped like a half-buried egg and steep at the lee end. These hills are called *s moutonnées*, a French phrase meani "sheep-shaped rocks," because of th resemblance to the backs of a flock of ep. The longer, gradual back-slope of th shows the direction from which the ier approached.

Continental glaciers tende o move faster and to spread farthest whe he land lay lowest. Thus, when the ice e upon

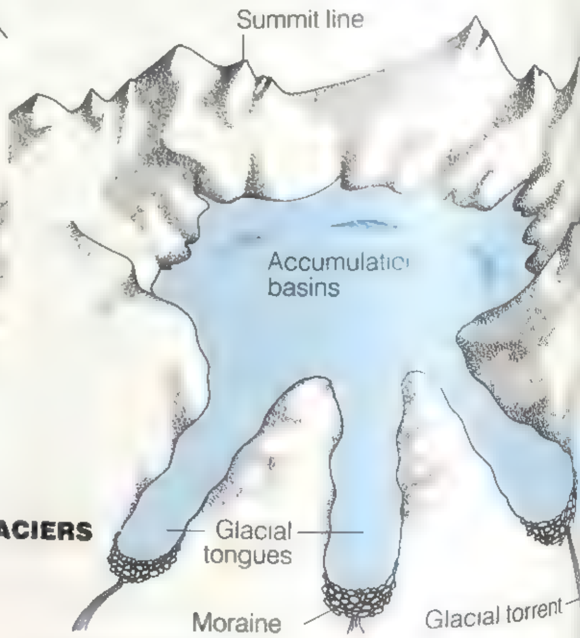
Mountain glaciers do not all form or move in a uniform way. Th strations below and on the opposite page show four main types of mountai ers.

VARIOUS TYPES OF GLACIERS



Pyrenean type

Hanging glaciers in the circque of a former larger, and more important glacier.



Scandinavian type

One collection basin feeds many glacial tongues.

mountain [illegible]ers, it made its way through the lowes[illegible] [illegible]tion of these barriers and scoured t[illegible] out as deep U-shaped valleys, ope[illegible] both ends. The various "notches[illegible] [illegible]e White Mountains of New Hampsh[illegible] [illegible]e formed in this manner.

On l[illegible] [illegible]and, the ice spread farthest down the [illegible] [illegible]iver valleys, like that of the Miami R[illegible] [illegible] Ohio. Where isolated hills stood in [illegible] [illegible], the ice sometimes flowed to either side of the obstruction, forming two lobe[illegible] [illegible] hills of upper Michigan and Wiscons[illegible] [illegible]ght about such a diversion of the ic[illegible] That is why the hills of southeas[illegible] [illegible]isconsin are free of deposits laid dow[illegible] [illegible]aciers, although they were surround[illegible] [illegible]e at one time or another.

Con[illegible] [illegible] ice sheets created most of our large lakes by hollowing out enclosed basins in [illegible] [illegible]id rock. The locations that lent the[illegible] [illegible] particularly to this deep scour we[illegible] [illegible]stream valleys where rocks were we[illegible] [illegible]d or where closely spaced natural [illegible] made plucking easy. Great lobes of [illegible] [illegible]ged out the basins of each of the Grea[illegible] [illegible]. The lake basins hollowed out by i[illegible] [illegible]es in low hill country have irregula[illegible] [illegible]ly shapes. A good example is Lake W[illegible]nipesaukee, in New Hampshire, wi[illegible] [illegible]ong bays and its 375 islands. On flatter land the basins are broad and shallow, as in the case of Lake Erie.

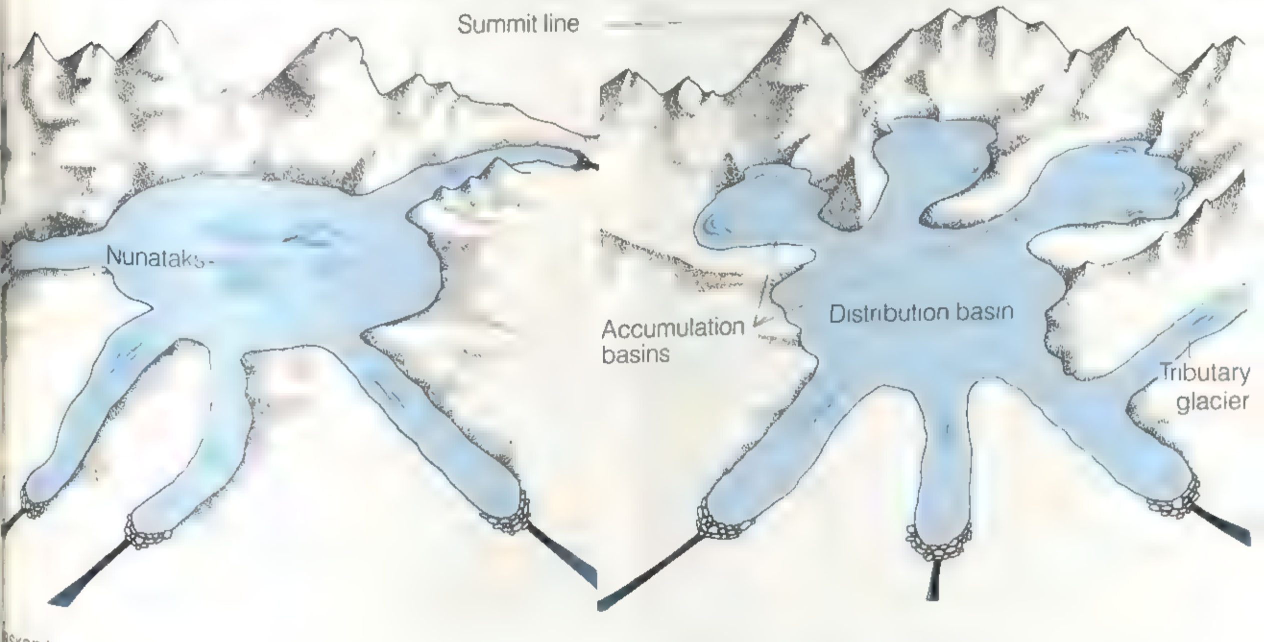
Continental glaciers also brought about important changes in the landscape because of their weight. They caused the underlying crust of the earth to be depressed as much as 280 meters, according to some estimates. Later, as the ice receded, the earth would "recoil" to more or less its original level.

GLACIAL DEBRIS

The name *glacial drift* is given to the material transported by glaciers and ultimately deposited upon the land. Unsorted rock debris deposited directly from the ice is called *till*. This contains fragments of all sizes, from tiny particles to huge boulders.

DEPOSITS OF ALL SIZES

Boulders ride along on and in the ice more or less undamaged, although some at the glacier bottom may be smoothed away on one or more sides. Frequently they are carried far from the ledges where they were formed and are dropped in areas where other types of rock predominate. Such wandering rock fragments are called *glacial erratics*. Some erratics are left delicately balanced on ice-smoothed ledges. They



[illegible]skan type

[illegible]ome of ice, surrounding nunataks, flows into [illegible]y glaciers

Himalayan type

Many accumulation basins feed a distribution basin which empties into glacial tongues

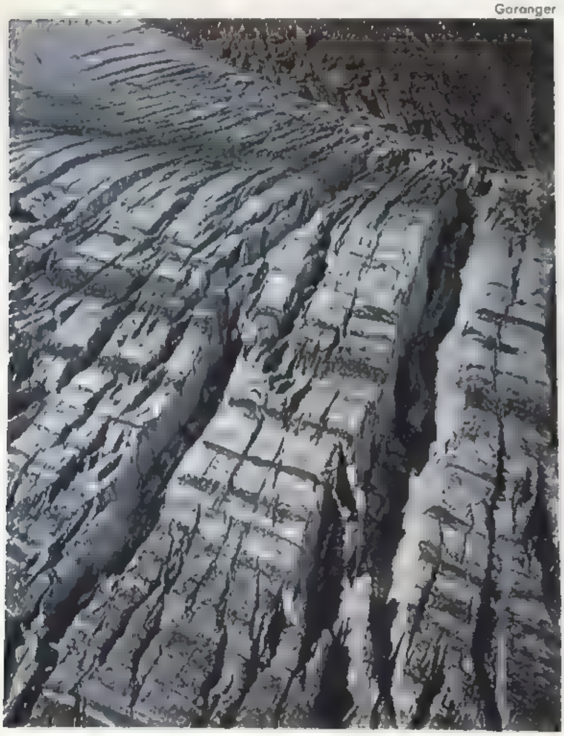
become perched boulders or rocking stones and are generally local curiosities. In many places boulders have been spread over the countryside in the form of a fan. The boulders are most numerous along the central portion of the fan.

In some places the bottom part of a glacier has become so filled up with debris that the ice of the glacier cannot transport it all. Part of the debris remains upon the land as the ice flows over it. This type of deposit is called *ground moraine*. It forms gentle and irregular undulations. Ground moraine, left behind by advancing ice sheets in the Pleistocene epoch, covers much of the glaciated area from Ohio to Montana. It is also found in the landscape of northern Germany, Poland, and the Soviet Union.

Here and there the till has been built up in long streamlined hills, resting upon the ground moraine. These are known as *drumlins*. Their surfaces are smooth and rounded. On a map they appear as oval hills from less than a kilometer to three kilometers or so long. They occur in groups of several hundreds in eastern Massachusetts, upstate New York, and southeastern Wisconsin. In the flat portions of Ohio, Indiana, Illinois, and Iowa, the till filled in old rock valleys, forming a till plain.

Wind, moisture, and an irregular valley floor all lead to the formation of deep crevices in many glaciers.

Goranger



Till that was pushed up and dumped by the advancing ice edge of a continental glacier sometimes formed rude ridges and hummocks. This formation is seen chiefly in belts of hummocky land, 1 to 15 kilometers wide, that can be traced cross-country for hundreds of kilometers. They are known as *end moraines*. In the United States, they are common on Cape Cod, Massachusetts, Long Island, New York, and from Ohio to Montana. Presumably they represent places where the supply of ice coming from Canadian regions temporarily equaled the rate of melting. All the ice-borne rock fragments were thus concentrated in one area. In some places these till ridges lie on earlier gravels or peat swamp beds, and these in turn are on top of still earlier tills. Evidently the ice advanced and retreated in these regions again and again.

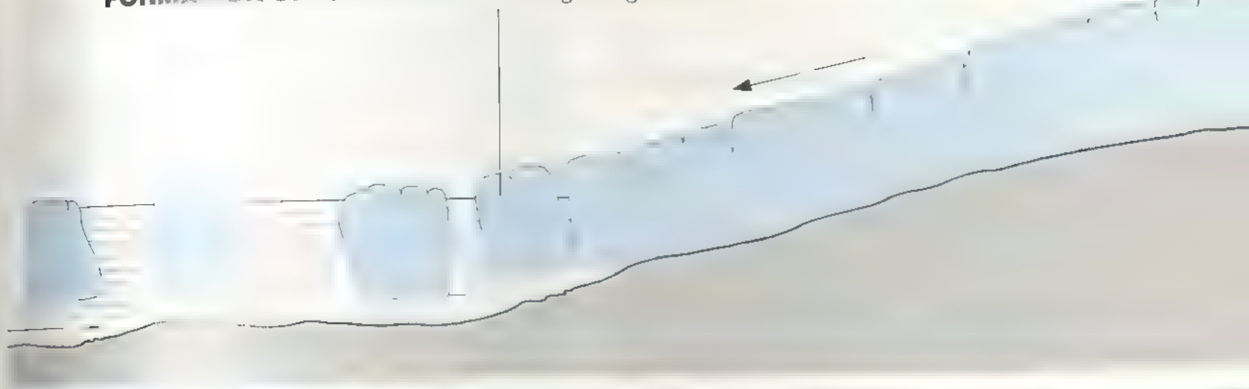
ACTION OF MELT WATER

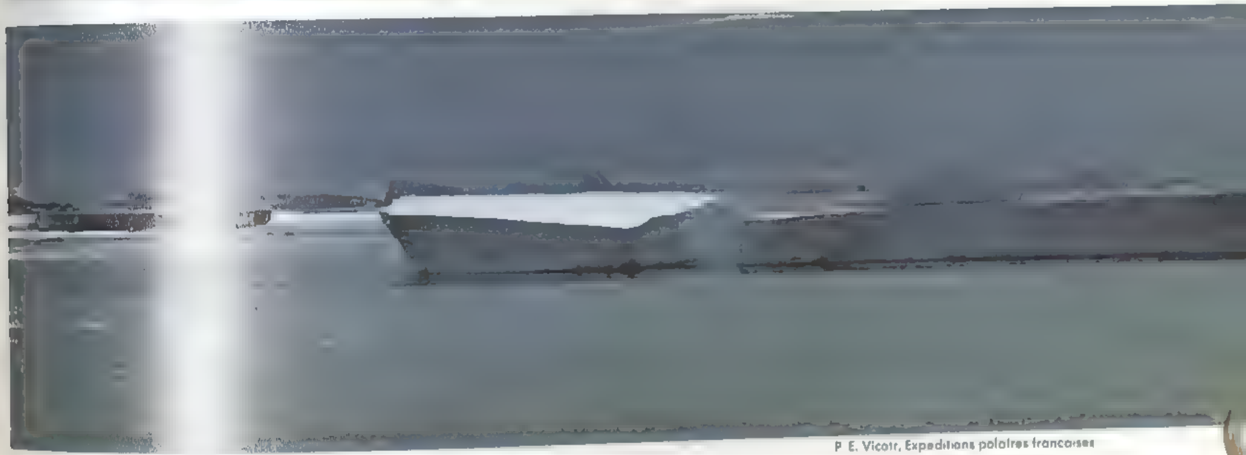
Much of the till carried in the ice was picked up by rivers of melt water, and deposited later. Such accumulations are called *outwash*. The rock fragments making up the outwash have been sorted out according to size by the melt water. For example, when the water flowed swiftly in narrow channels only coarse gravel came to rest. When its flow was sluggish, fine sand and silt were deposited.

In some cases melt water flowed through the ice in tunnels or at the bottom of crevasses in the area of dissipation. The channels had steep walls of ice holding the water in on both sides. Rounded rock fragments were deposited on the channel floors. When the ice melted away, the channel floor deposit was left high and dry as a long, winding ridge. These formations, called *eskers*, are found in considerable numbers in the northern United States and Canada.

Melt water streams flowing on the surface of glaciers or in channels within them built up outwash deposits at the margins of the ice mass. When the glacier melted, these deposits remained as sand and gravel hummocks, called *kames*. The hollows between the kames represent places where

FORMATION OF ICEBERGS





P. E. Victor, Expéditions polaires françaises

When an ice sheet reaches the sea, larges masses break off and float away, becoming icebergs. However large these icebergs may look—these floating "ice tables," for example—about 80 to 90 per cent of the berg is submerged.

thick masses of ice prevented the laying down of deposits. Sometimes gravel and sand were deposited along the margin of the ice in a sort of continuous shelf, called a *kame terrace*.

Sometimes the sand and gravel outwash of continental glaciers would be carried far beyond the ice itself. The channels of the streams transporting it would follow an erratic course. Often a stream would split into branches. Then the branches would unite and form a single stream again. In this way deposits forming a braided pattern were laid down. If the melt water came to an already existing valley, it would fill up the valley with sand and gravel, forming a *valley train*. Later the melt water stream would stop flowing, leaving the valley train as a memento of its passing. Modern streams have cut away large parts of these valley trains.

If the melt water stream did not come upon a convenient valley, it would build up a gently sloping deposit of gravel 3 to 40 kilometers broad as it spread out over the land and then stopped flowing. Expanses of thinning ice sometimes got buried under the masses of outwash laid down in this way. Years later, the buried ice would melt. The overlying sands or gravels would then sink down, forming hollows called *kettle holes*. A lowland dotted with kettle holes is called a *pitted plain*. Many of the hollows in such a plain now hold small ponds.

Lakes at the margin of continental glaciers would be fed by melt water, carrying

quantities of clay and silt. In the summer months, the water of such a lake would be stirred up by the melt water currents entering it and also by wave action. Only the comparatively coarse silt particles would settle out. The lake would freeze over in winter. The water under the ice would then be quiet, and fine clay particles would be deposited on the lake floor. All this would produce a silt-clay layer, called a *varve*, representing the deposits of a single year. By counting the total number of varves in certain areas, geologists can calculate how long it took for silt-clay deposits to be built up.

ICEBERGS AND ICE ISLANDS

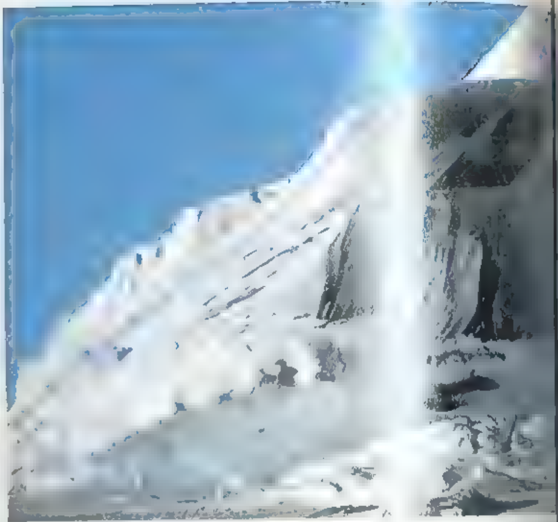
When a glacier or ice sheet reaches the sea, large masses of it often break off and float away. These pieces of floating ice are called *icebergs* ("berg" in German means "mountain"). Ice "mountains" vary greatly in shape and in size, from that of a small house to a length of several kilometers. However, a flat, or tabular, iceberg from the sheet that covers Antarctica may be as much as 150 to 300 kilometers long—a veritable floating island.

Huge as an iceberg may look, the part we see above water is really very small. About 80 to 90 per cent of a "berg" is submerged. It is estimated that for every three meters of ice above water, there are 25 to 30 meters of ice below the surface of the sea. Thus, if an iceberg towers 90 meters over the waves, its base lies nearly one kilometer under the water.

Such tremendous ice mountains may be a serious threat to shipping. This is especially the case with Arctic icebergs, which float southward between Greenland and the North American mainland into the North Atlantic Ocean. April, May, and June are the worst months, when icebergs reach the waters off Newfoundland.

Ships have been sunk in collisions with icebergs. The most famous disaster of this kind was the sinking of the ocean liner *Titanic* in April 1912, when over 1,500 lives were lost. International iceberg patrols watch the North Atlantic steamer lanes and issue warnings of the approach of icebergs.

Today, ships easily avoid icebergs by means of onboard radar. Airplanes and orbiting artificial earth satellites also keep track of icebergs and report their size and movements.



A large iceberg, or ice mountain, having broken off the ice sheet, floats near Antarctica.

After passing south of Newfoundland, Arctic icebergs soon begin to melt as the ocean becomes warmer. Internal strains also break them up. The ice mountains then often vanish without a trace, except for the rocks they once held dropping to the sea bottom.

Large tabular icebergs are sometimes called *ice islands*. They occur in both the Arctic and Anatarctic but are more long lasting in the Arctic. Ice islands are often used as drifting research stations used to study not only the structure of icebergs but also the winds, waves, and currents of the polar seas.

In the Arctic, ice islands typically form when large pieces break off the ice shelf at Canada's Ellesmere Island. They drift in the clockwise current of the polar sea until running aground. One three kilometer-square ice island was established as a research station by U.S. scientists in 1961. Named Arctic Research Laboratory Ice Station 2, it was used until 1965 when it ran aground off the eastern coast of Greenland.

SEASHORES

by Francis P. Shepard

Every year millions of people make their way to the seashore to enjoy the cool ocean breezes, bathe in the sea, and sun themselves on sandy beaches. How many of them realize the dramatic processes of change that are constantly going on at this meeting place of land and sea? Certainly it would add greatly to the interest of a stay at the beach if one knew of the mighty forces at work carving the land bordering or encroaching upon the sea. Among the most powerful of these forces are the waves and currents of the ocean, eroding here and depositing there.

Waves are present all over the surface of the great oceans, but our chief contact with them is along the shore. They are complicated formations as they occur in nature. On page 204, we show a theoretical water wave, which does not indicate this complexity. Note, in the diagram, that the high point of any wave is called the *crest* and the low point the *trough*. The *wave length* is the distance between two crests. The *wave height* is the vertical distance from trough to crest. The name *wave period* is given to the time it takes for two successive crests to pass the same point.

WAVE MOVEMENT

A wave may appear to move forward rapidly, but actually the water particles it contains do not keep pace with the apparent movement of the crests. Instead, these particles go around more or less in a circle though there is a very slight forward motion. You can see this for yourself if you throw a floating object in the water from the end of a pier beyond the *breakers*. You will see it move shoreward when the crest is passing and then back again in the trough of the wave, but usually with a net shoreward movement.

If you watch some wave crests advancing toward the beach, you will note that they move more slowly, get closer together, hump up to a greater height with steeper sides, and finally break. This change in the character of the wave is brought about as the water becomes shallower. At the place where the crest collapses, tumbling over like a waterfall, the waves powerfully affect the sea bottom. If you have ever been caught in a breaker, you have become aware of the strong downward push of the water. A large breaker is exceedingly dangerous for this reason. Unless you can jump up clear of the breaker you should always dive under it when you find it overtaking you. In this way you will get through the breaking wave before it can fall on you with much force.

Inside the breakers, the moving mass of water advances up the beach. For every forward motion there is a subsequent backward one. The forward motion, called the *uprush*, is somewhat stronger than the return motion—the *backwash*. It is also of shorter duration. As a result of the higher velocity of the approaching waves, larger objects on the sea bottom are likely to move shoreward. Because of the longer duration and lessened force of the outflow, small objects have a tendency to move seaward while larger ones are left behind. This accounts for a common—though not invariable—coarsening of material as one advances up a beach. Many beaches have gravel in the upper part and sand in the lower part.

ORIGIN OF WAVES

Waves are a good deal more complicated than would appear from the rather simplified explanation we have just given. This is partly because of their origin. They are generally started by winds, largely storm winds, blowing on the ocean surface and producing humps and hollows moving in the direction of the wind. The waves with longer periods move faster and maintain their undulations longer than those with shorter periods.

A great storm will often send these long-period waves several thousand kilometers beyond the point where it was centered. In their journey from one storm, waves encounter the wave products of other storms, and the motion of one set is superimposed upon that of the other. This is one of the reasons why waves are so irregular in period and height. When the crests from one storm reinforce the crests from another, high waves result. If the two counteract one another, small waves develop.

Waves continue in the same direction until they get into shoaling water. Here they are slowed in their progress. They are not parallel to the shore as they approach, but are diagonal to it. The net forward motion of the water sets up currents that move along the shore in the direction in which the waves are approaching. Such currents may attain relatively high velocities, up to several kilometers an hour, and may cut troughlike depressions along the shore. The troughs are a source of danger to bathers. They may have deep sides, and the strong currents that create them may carry swimmers beyond their depth.

RIP TIDES

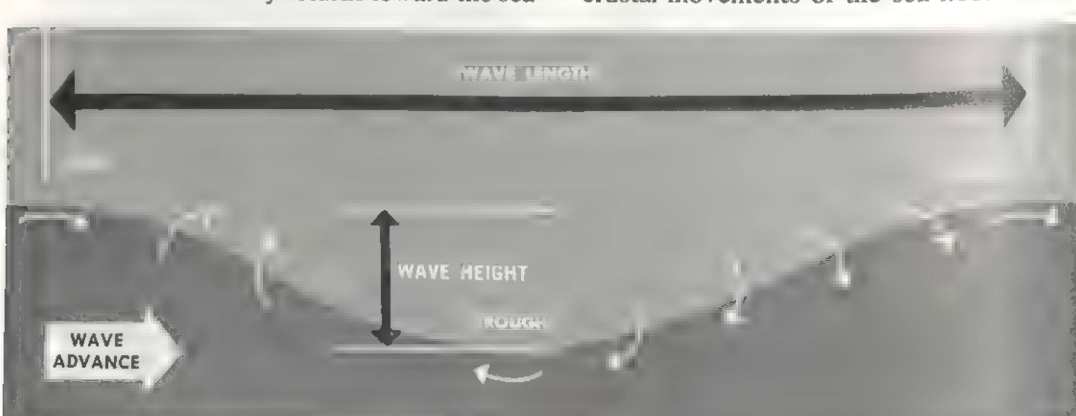
Because the net movement of the waves is landward, there must be a return current or else the water would keep piling up higher and higher along the shore. The return current is known as a *rip current*, or popularly, as a *rip tide*. It is in many ways even more dangerous than the breakers. The water ordinarily returns toward the sea along certain lanes, which are partly the result of the irregularities of the sea floor and partly due to coastal irregularities. Rip currents move diagonally outward from top to bottom of the water mass, rather than as "undertow."

After going seaward to a point where the water deepens considerably, the currents confine their energy to the surface or near surface. Presently they begin to spread or fan out. The water then moves along the coast and returns shoreward, though at lesser speed than before. Rip currents cut small gullies in the sea floor. Because this causes the water to be deeper, the waves often do not break in this zone, but show an agitated appearance.

Rip currents undoubtedly cause more deaths by drowning among surf bathers than any other factor. Their velocity is often so great that even moderately good swimmers cannot make headway against them. Seized by panic when they find they cannot reach the shore, most people do not realize that all they have to do is swim parallel to the shore until they can escape from the rip. This is the only safe procedure unless one is a good enough swimmer to allow oneself to be carried out beyond the breakers and then return along a different lane.

VIOLENT WAVES

Occasionally great surges of the sea wreak havoc on the coast they encounter. They are usually called *tidal waves*, although they have nothing to do with tides. They are caused principally by sudden crustal movements of the sea floor. These



either push up the water surface or suck it down, according to the direction of the motion on the bottom of the sea. Most scientists refer to the resulting waves as *tsunamis*, after the Japanese word meaning "large waves in harbors."

Tsunamis differ from ordinary wind waves in having very long periods between crests—commonly fifteen minutes or more. Since their crests are kilometers apart, they produce no noticeable effect out at sea. It is only near shore that they grow to terrifying heights. Often they rise like a tide, only much faster and higher. As a result, they come in over the entire beach, over sea walls, and even into harbors.

Another disastrous type of wave is caused by hurricanes or other great storms. The winds drive the water up along the coast. They cause the sea level to rise as much as three meters and occasionally even higher. This has caused the flooding of many low-lying areas. Galveston, Texas, was devastated by such a storm tide in 1900. About 5,000 persons lost their lives.

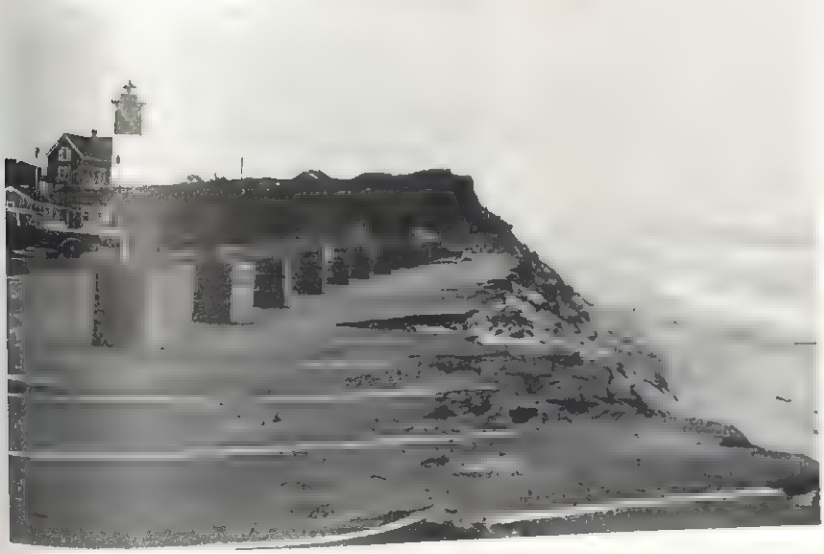
The sudden explosion of a submarine volcano or the sudden engulfment of a island can bring about even larger waves. In 1883, a large part of the volcanic island of Krakatoa, off the coast of Java, was engulfed after a series of violent eruptions rocked the island. Disastrous waves resulted. Thousands of people were drowned in the adjacent islands. The waves spread all over the world, and they caused loss of life and property damage in many widely separated places.

HOW BEACHES FORM

Waves and currents are the chief agents in the formation of beaches. Because waves push relatively coarse types of bottom sediment toward the shore under their advancing crests, they generally pile up sand above sea level along vast stretches of coast. This does not happen everywhere, however. On steep, rocky coasts, there is no platform on which sand can be deposited. In certain places, the adjacent sea floor has no sand supply. In other regions, the sea floor drops off so steeply that the waves are not powerful enough to move the sand shoreward against the mighty force of gravity.

Beaches are by no means stable. Most of them are constantly growing either wider or narrower. Many disappear completely during stormy periods, only to reappear when the storms are over. These changes appear to be related to the relative power of the uprush and backwash of the waves. When these are small, only the uprush has the power to move the sand, which therefore comes in onto the beach. During large

Mary M. Thacher/Photo Researchers, Inc



It is very difficult to alter the natural processes that form coastlines. Nature wins here: half of a parking lot built near the shore has been eroded by ocean waves.

©H. W. Kitchen from National Audubon Society/Photo Researchers, Inc

Land-building processes compete with land-eroding processes at the water's edge. Sand and other sediment is captured by grass roots, and land is built up. At the same time, surf action tends to wash away part of the coast

waves, on the other hand, the sand is carried by both the backwash and the uprush. The sand particles that move down the backwash are often caught in powerful rip currents and swept out into relatively deep water. In such cases, the beach retreats.

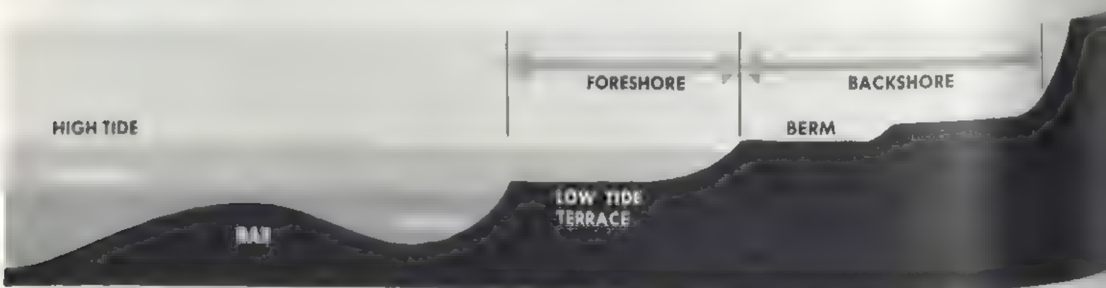
In many instances, changes in beaches can be traced directly to the work of man. In order to develop harbors along a straight coast, where no natural protection exists, walls called *jetties* are built out into the sea. They serve to stop the natural drift of sand along the shore. If the current is moving principally in one direction, the sand piles up on the side from which the current is coming. The beach becomes so wide that the houses originally built near the water are now far away from it.

On the other side of the jetty, the beach becomes "starved." The sand that would normally be supplied to it by the longshore currents and by the shoreward sand migration from the small waves is trapped by the jetty. The result is that the winter storms cut away the beach and it is not replaced.

In many cases, the "starving" of the beach results in the destruction of houses built near the water. It may even bring about the loss of the entire beach. At Redondo, on the south end of Santa Monica Bay, California, the cut in the lee (protected side) of the curving harbor jetty caused the loss of an entire city block before the coast could be stabilized. To the east of the Santa Barbara, California, harbor jetties, the beaches were cut away for many kilometers, causing great loss to resorts that had been built on that side. To the west, on the other hand, the beach grew very wide.

The cutting away of beaches in the lee of a jetty does not go on indefinitely, because after a time the indentation of the coast serves as a natural protection against

Divisions of a typical beach



further cutting. An equilibrium is reached as the beach receives a supply of sand from the other direction during occasional reversals of the longshore currents. Also a certain amount of sand is carried around the end of the jetty to the lee side.

PARTS OF A BEACH

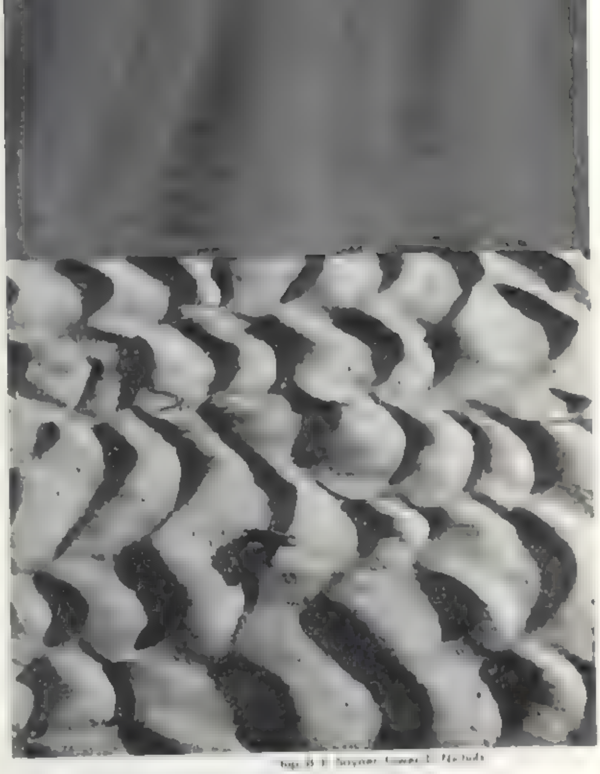
Any wide beach has several distinct divisions. At the top, the beach has a more or less horizontal surface called the *berm*, part of the backshore. This slopes slightly landward in coarse beaches and gently seaward where the sand is finegrained. Seaward of the berm the relatively steep slope is called the *foreshore*. The slope of this section also depends on the size of the sand grains. It may be as much as ten or fifteen degrees in the case of coarse sand beaches. Fine sand beaches slope only from about one to three degrees.

When there are no appreciable waves, the high tide covers most of the foreshore slope. During periods of large waves, the uprush carries the high tide over the berm edge. On many beaches, the low tide exposes either a terrace or a trough and bar. Both the terrace and the trough and bar are likely to be cut away during periods of high waves. The trough and bar then move out into deeper water, where they are located well below the lowest tides.

SAND MAKEUP

Beach sands along the continents consist mostly of rock minerals, particularly quartz. This mineral is almost entirely lacking in the beaches of oceanic islands in the tropics. Although many of the white sands in these places look rather like quartz, they really consist of coral and shells, ground up by the action of the waves.

Under ordinary conditions, the foreshore of fine sand beaches is firm enough to support an ordinary car. On the other hand, only vehicles such as tractors or jeeps can be driven on a coarse sand beach. The berm of even a fine sand beach, however, is apt to be treacherous, and even the foreshore is unsafe if the tide has very recently covered it. There is an interesting contrast between beaches on the east coast of Florida. At



Beaches often have several distinctive markings
Top: backwash ripples formed by retreating waves
Bottom: ripples produced by currents

Daytona, the fine quartz sand beach is so firm that it has been used for auto racing for many years. On the other hand, the shell beaches of Miami, Palm Beach, and Fort Lauderdale offer no support for a car. Most of the long beaches of Texas are excellent for cars because they are composed largely of fine quartz sand, but a jeep is required to travel on the sands of Padre Island, to the south, because these sands consist mostly of shells.

BEACH MARKINGS

Closer examination of a beach reveals many interesting phenomena. On fine sands, the backwash of the retreating waves develops *ripple* marks, which are low in height and almost always about 45 centimeters from crest to crest. In the pools left behind in the ripple troughs, the mica which temporarily floats in the water settles to the bottom. Such troughs often glisten in the sunlight because of the reflection from the flat mica surface. These backwash rip-

P. H. Kuenen

Rill marks. These have been cut in the beach at low tide by the run-off of water buried in the sand.

ples are not found in coarse sand because the grains fall back in place after the water has retreated.

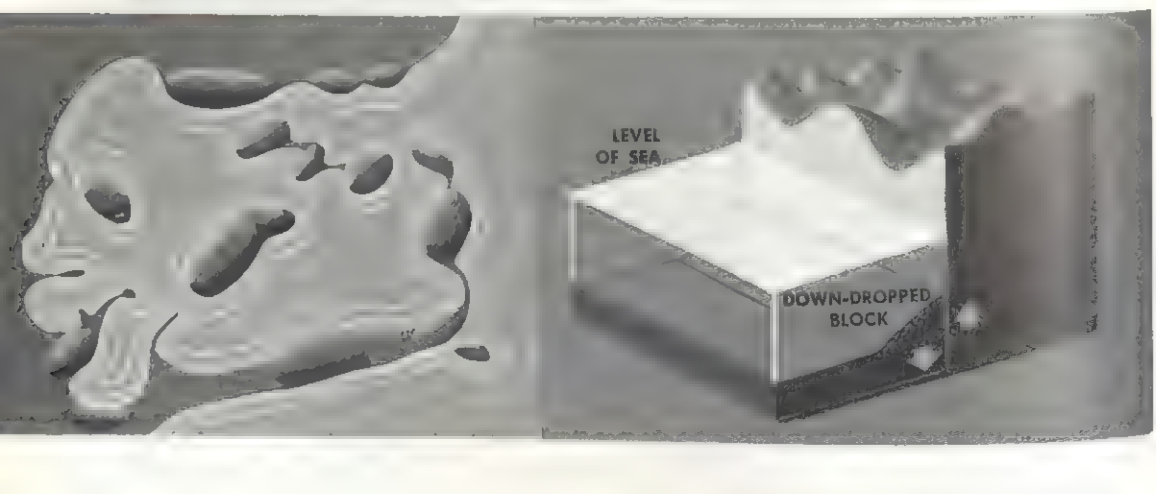
Another type of ripple appears at low tide, when the troughs of the longshore currents and rip currents are partially exposed. Current ripples are found in both coarse and fine sand beaches. They are formed by the current flowing along the troughs and ordinarily run at a wide angle to the backwash ripples. These current ripples are much more pronounced than the backwash variety and the distances from crest to crest are shorter. Their steep side is away from the current. If you stand in shallow water along the shore in an area with small waves, you can often see two sets of ripple marks on the sandy bottom. One has crests extending at right angles to the shore. The crests of the other are parallel to the shore. The first is due to longshore currents; the second, to the back-and-forth movement of the small waves moving in and out from the shore. If the bottom is covered with fine sand, these wave ripples are closely spaced, about seven or eight centimeters from crest to crest. They are rather widely spaced—commonly from 15 centimeters to three meters or so—when the sand is coarse.

Another curious feature of beaches is a symmetrical series of short ridges, each extending down the foreshore and coming to a point. These ridges are called *beach cusps*. The interval between cusps is almost exactly proportional to the size of the waves that produced them. During storms, widely separated cusps, 30 meters or more apart, are brought about. Under small wave conditions, they are much closer together. The smallest cusps are found on the beaches of small lakes, where they may be only a few centimeters apart.

Various other markings are found on the sand. At the top limit of the uprush, where the water hesitates before returning seaward, fine material is deposited and a thin line is produced. This line, called a *swash mark*, generally consists of mica or plant fragments. If a new wave comes to a greater height, the swash mark disappears and a new one is formed at the higher level.

A diamond pattern of dark streaks is produced by the backwash when small peb-

Left: a series of drumlins—oval hills formed by glaciers—which became islands as the sea penetrated the general area. Right: the border of the upraised block in the fault below has become the coast. The down-dropped block is under water.



bles or shells divert the return flow and concentrate it along diverging lines. Sometimes these diamond patterns appear to be due to small sand crabs which burrow beneath the surface and push up small antennae to catch organic material drifting past. The animal's antennae have the same effects as the shells and pebbles mentioned above. They serve to divert and concentrate the return flow.

At low tide, the water beneath the sand migrates seaward, coming to the surface along the lower beach and developing small streams. These in turn produce miniature valleys, called *rill marks*. They resemble on a small scale the valleys cut on land by streams.

Other markings on beaches are due to various forms of life. Worms eat their way through the sand in order to extract the organic material it contains. When they are near the surface, they often produce small ridges. Other organisms crawling over the sand bring about small depressions. Holes are produced by the digging of crabs. The excavated material is built up into cones, resembling miniature volcanoes. Some of the crabs spray out the sand in a pattern of lines, radiating outward from the excavation point. Certain craters produced by crabs in tropical areas are of impressive dimensions.

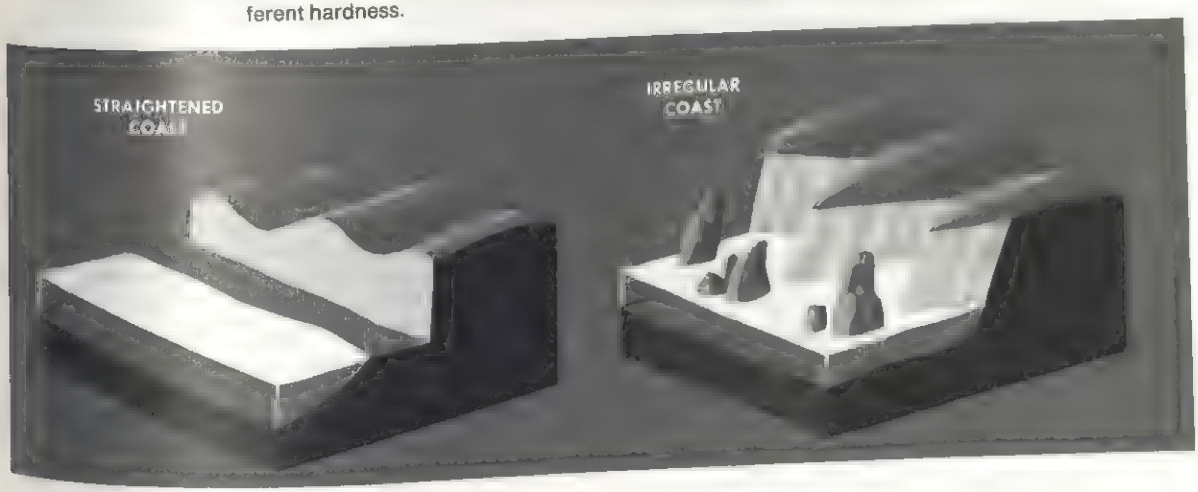
BEACH LAYERS

Most beach sands are stratified—that is, made up of layers. You can often see these layers when a ditch has been cut into the beach. They are generally caused by the variation in the amounts of dark- and light-colored minerals in the sand during the building up of the beach. The larger waves produce a sand with more dark minerals, since they tend to be heavier than light-colored ones and the larger waves can transport them more readily. Other layers are due to a concentration of mica, brought about only when waves are very small.

When one digs down to the bottom of a beach, one often exposes a very black sand, particularly along the base of sea cliffs or sea walls. This black layer is the result of especially severe wave conditions, because of which all of the light-colored sand has been carried out to sea, leaving only the heavier mineral concentrates. Black sands often contain valuable minerals such as wolframite.

When sand has recently accumulated on a beach, it is likely to contain an excess of air. As water pours over this new sand, the air may be concentrated in pockets, which bulge up like blisters, producing small *domes*. If one prods these domes, the air escapes and they collapse.

Coast formed by wave action. If coastal formations attacked by waves are relatively uniform, a straight wave-cut coast develops. Irregular contours develop if rocks are of different hardness.



COASTS AND SHORELINES

So far we have been dealing with processes of change involving comparatively small areas—local beaches. Changes on a far grander scale constantly modify the contours of the coasts and shorelines of the world. Before we discuss these changes, it will be helpful to give a few definitions. A *shoreline* is, literally, the "line" where water and land meet. The *shore* is something quite different. It is the zone between low tide and the inner edge of the wave-transported sand. The *coast* is a broad, rather indeterminate zone landward of the shore. It includes sea cliffs, coastal terraces, and the broad lowlands adjacent to the shore. There would be no purpose in taking up shorelines and coasts separately because the two overlap to such an extent. They exhibit unmistakable features which serve to identify them, even in places where the sea that had produced them has long since vanished.

If we examine coastal maps from various parts of the world, we find that there are two principal types of coasts. One has a more or less straight shoreline, such as we find along much of the coast of California and along the outer coast of Texas. The other is deeply indented, or irregular, and shows many bays and promontories.

One of the earlier classifications of coastlines included most of the straight shorelines in one category, labeling them coasts of emergence. Most of the irregular shorelines formed a second category—the coasts of submergence. It was argued that the submergence of valleys and ridges would cause the sea to come up the valleys, making bays and leaving the ridges as promontories. On the other hand, it was maintained, if the coast was elevated, it would raise up the flat sea floor and cause it to be subjected to surf action. Later, the breakers would build up a sand ridge, called a *barrier island*, above sea level. This would produce a straight coast, because barrier islands are predominantly straight. If a coast was neither submerging nor emerging, it was classified as neutral. Among the examples given for this kind of coast were deltas, which are built out into the ocean, and volcanoes, which build seaward as they grow in bulk.

The very simple picture suggested by this classification was quite generally accepted by geologists in the early part of the twentieth century. Then some of us began to test the classification, and found that the theory on which the classification was based proved to have serious flaws.

In the first place, we have come to realize that the sea level has been very unstable during the past million years or so. The most recent event has been a considerable rise in sea level, accompanying the melting of the last great continental glaciers. This rise may be still continuing, although, if this is so, it is proceeding very slowly. It was going on actively up to some 6,000 years ago—that is, up to the time of the building of the early Egyptian pyramids. Such a rise has of course drowned (submerged) all low-level valleys around the coasts of the world and has therefore made them all coasts of submergence, except in the rare cases where a recent uplift has counteracted the effect of sea-level rise. It has been shown, too, that many of the straight coasts of the world, such as that of Texas, result from a sinking process combined in its effect with the submergence due to sea level rise. The barrier islands of Texas have been formed as the land sank or the new level rose.

Even many of the so-called neutral shorelines have proved to be badly classified. Many of the great deltas of the world are by no means neutral. We know now that they are actually subsiding, so that they would come under the classification of shorelines of submergence. Similarly, volcanic coasts are subsiding in many areas as the result of the great weight of the volcanoes on the earth's crust.

Such difficulties as these have made it necessary to develop a more practical classification of the various types of shores and coasts. I proposed such a classification and it has been widely adopted. I give a brief outline of it in the following pages.

First, I divide all coasts into two major groups. In the first, I include the coasts that owe their general shape to nonmarine agen-

cies—that is, processes in which the action of waves and currents plays no part. Only after these coasts have attained their present contours have the waters of the sea penetrated them. My second group includes the coasts that have been shaped largely by waves and currents.

COASTS FORMED BY NONMARINE PROCESSES

Many coasts owe their general shape to the effect of running water on land areas. Through erosive action, streams carved out valleys as they made their way to the sea. The waters of the sea have now penetrated these valleys, but their general conformation remains more or less unchanged. Chesapeake Bay along the eastern coast of North America is an example. Each tributary valley gouged out by running water in ages long past has become a separate arm of the sea. An oakleaf pattern has resulted.

The running water of rivers carries sediments and builds up deltas at the mouths of rivers. If the delta-building goes on at a faster rate than the sea-level rise, the coast is extended into an arc or a birdfoot, such as we find at the mouth of the Mississippi. A delta of this type grows outward as a cluster of long, narrow peninsulas, joined together upstream somewhat like the toes of a bird's foot. Several deltas may merge and form a continuous plain along the coast. In such cases, a relatively straight river-deposition shoreline may exist. Much of the east coast of New Zealand's South Island has originated in this way.

Glaciers have also helped to shape the coast. If a coast has been glaciated—that is, covered at one time by a great glacier of the Ice Age—its present appearance gives many indications of the action of the ice. Deep valleys, called *fiords,* were cut out by the ice well below sea level. When the ice retreated, the sea came up into these valleys.

In some localities the glaciers left deposits in the form of elongated ridges and hills, called *moraines*. The rising sea level brought the shoreline up against these glacial hills. Generally, the sea has so modified

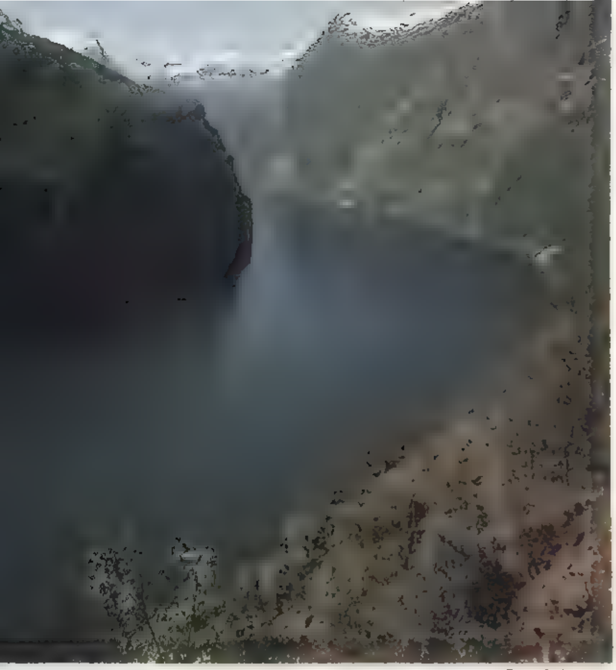
Jerome Wyckoff

Moyl n

Top: coast of emergence east of North Berwick, England. This topography includes an old, uplifted, wave-cut terrace and a new terrace being cut below the cliffs. Bottom: barrier reef in the South Pacific. Barrier reefs are formed by coral growing outward far from the shore

the shoreline that the original outline of the moraine no longer exists. There are some exceptions, however. For example, the inner, protected shore of Long Island, New York, still shows some of the original glacial-moraine shoreline.

Glacial deposition also resulted in the formation of oval hills, called *drumlins*. They were elongated in the general direction of the ice movement. The drumlins in what is now Boston harbor formed islands as the sea penetrated the area. These drum-



Björn Bolstad/PR

Norway's Geiranger fiord is a deep valley that, like other fiords, was cut out by glacial ice below sea level and later flooded by the sea.

lin islands have been so little modified by the subsequent action of the sea that their oval shape constitutes the shoreline.

At least two types of coasts owe their form to volcanic activity. The first, found largely among islands, has a circular or oval outline, representing the base of the volcanic cone. The Hawaiian Islands offer some fine examples of this type of formation. A second type is concave in general outline. It is due to the collapse of old volcanoes or to explosions that have blown away one side of a volcano. Such coasts are quite common in Japan, the Indonesia area, and the Aleutian Islands.

Along the rim of the Pacific, there are many areas where the coastal contour is due primarily to movements of the earth's crust. Faulting, in which one block of the crust moves against another block, is responsible for many of the straight shorelines in the Pacific area. The border of the upraised block constitutes the coast. The down-dropped block is beneath the sea. Because of the general steepness of fault surfaces, the sea bottom slopes off rapidly along most fault coasts. For example, along the west coast of the Gulf of California, it is possible to cruise along the shore with 300 meters or more of water under the vessel. Coasts may also be due to folding, or the bending of the earth's crust. When the sea penetrates such areas, a series of islands and intervening sounds are formed. The islands represent the upfolds, or anticlines; the sounds, the downfolds, or synclines.

COASTS FORMED BY THE SEA

Along most coasts of the world, the shorelines have been greatly modified by the effect of waves during the time of the last rise in sea level. Waves may either cut back the coast or build it out by depositing material upon it.

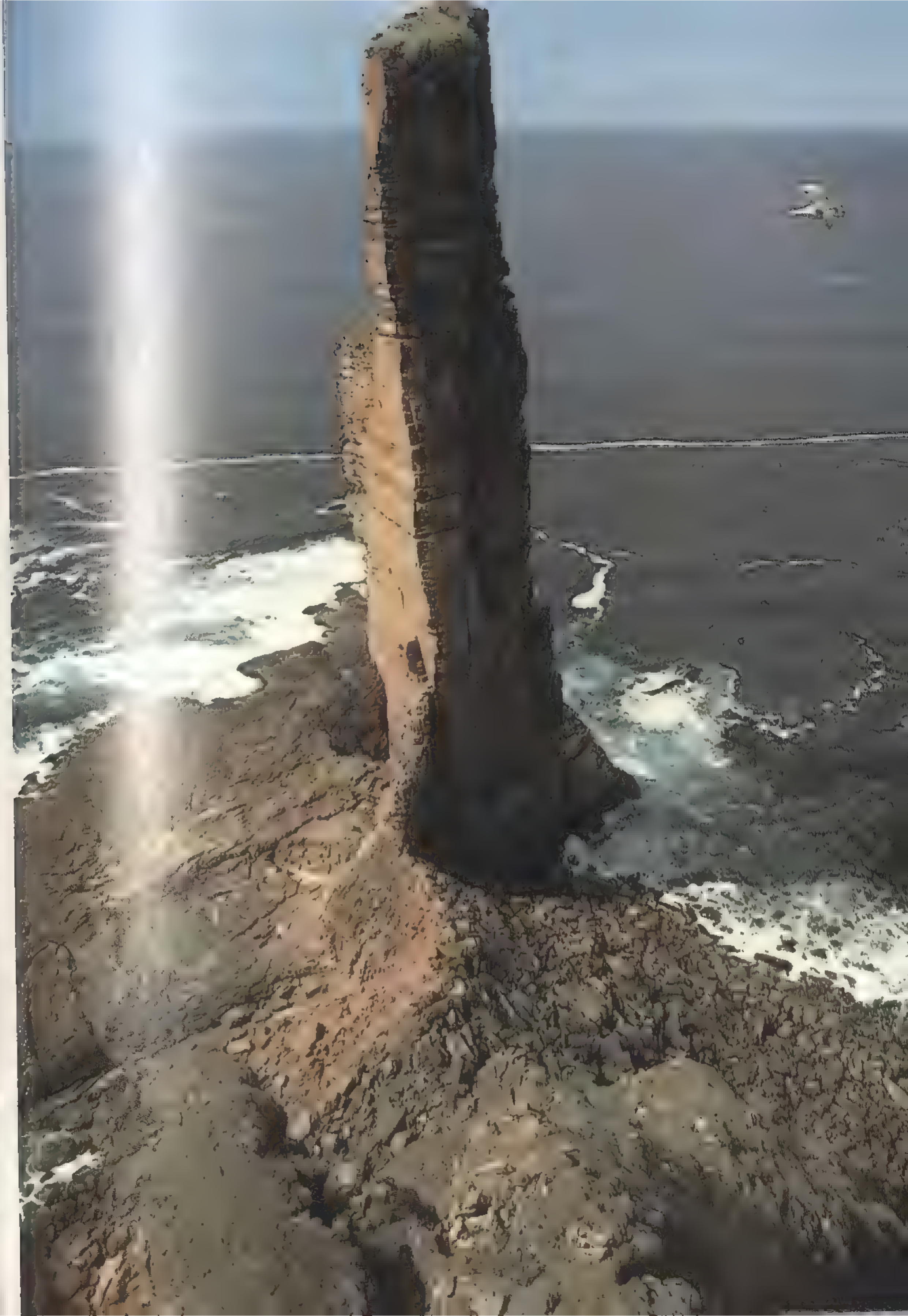
Where the coast has been clearly worn back by the waves, it is straight or has many small indentations. We do not find the deeply penetrating bays characteristic of drowned river valleys and of fiords. The straight wave-cut coast develops where the coastal formations attacked by the waves are relatively uniform and where the rocks are quite soft. The waves attack projecting points and wear them back. The chalk cliffs of Dover, England, are a well-known example of a straight-cut coast.

Where the rocks of a region are of different hardness, the waves cut back the softer portions, developing rounded coves and leaving the harder rocks protruding as headlands. At La Jolla, California, the cliffs that have been cut into the relatively soft Eocene formations to the north are quite straight. To the south, we find a projecting land body called Point La Jolla. The hard Cretaceous sandstone of this area has withstood more effectively the pounding of the waves.

The laying down of material by the sea has generally resulted in the straightening of the coast line. For example, the long smooth curve of the outer coast of Texas is the result of the deposition of a sand beach, which grew into a barrier island, one and one-half kilometers or more in width. The barrier lies across a highly irregular

Georg Gerster/PR

This rock pillar rises nearly 140 meters on the coast of Hoy, one of the Orkney Islands. It was formed by wave erosion of the coastal cliff.



Maylin

Aerial view of a coral atoll. Atolls are formed when a volcanic island surrounded by coral sinks.

drowned river valley coast, which extends along most of the barrier length. Similarly, the straight New Jersey coast results from a barrier built across the drowned river valleys. These valleys are recognizable on the inside of the barrier. In other cases, the deposition has simply formed a sand beach across the mouth of a bay, connecting the headlands on either side.

Deposition may develop irregularities, particularly where sand spits are built up from a relatively straight coast. The spits apparently form where there are two adjacent eddying currents and a zone of quiet water in between. If the sediment that is transported by the current is carried into the dead spot, it is deposited.

In some areas, especially in the tropics, the shore is extended as aquatic plants grow out into the water. These are not true oceanic seaweeds, or kelp, but land plants that can live in salt water. The mangroves are the best examples of these plants. They have barbed seed pods which drop from the extended branches into the adjacent water. They plummet to the bottom and there they become rooted. After the plants become established in the shallow waters along a coast, mud is gradually transported into the area and deposited between the roots. Eventually, the region is built up to the sea surface. Such coasts are usually marshy.

The coastal formations called *serpulid reefs* are due to certain worms, belonging to the family Serpulidae. These worms attach themselves to the shallow bottom near the shore or to coastal rocks. They extract lime from the sea water and form a tubelike frame, which gradually builds up toward the surface. Oysters develop similar reefs in bays of rather low salt content. These reefs may grow to the surface and become a part of the land, partly as the result of wave activity.

Another type of coast, very common in the tropics, is that formed by *coral reefs*. In many places, they merely produce a rim around a coast of different origin. Reefs of this type are common around volcanic islands, whose volcanoes have become extinct. The corals grow along the shore. They develop a shoal platform called a *fringing reef*, which is partly uncovered at low tide. Coral cannot grow above low tide, but storm waves may throw up enough debris on the inner portion of the reef to form a low terrace above the reach of ordinary tides. Elsewhere, these terraces rise somewhat above sea level because of local uplifts of the islands.

Barrier reefs form where the coral grows well beyond the coast, leaving a quiet and often deep lagoon on the inside. In some places, these reefs have been built above sea level by the waves or have been sufficiently raised so that human habitations can be found on them. Generally, however, reefs are exposed only at low tide.

The Great Barrier Reef of Australia extends for 2,000 kilometers along the coast and has a width of up to about 150 kilometers. In places it projects above the water, forming islands. Most of these are low and sandy. They are known as *faros*, or *cays*–or *keys*, as they are called in the United States.

Ring-shaped coral islands called *atolls* are found in profusion in the southwest Pacific.

The coastal types that we have included in this brief survey are probably the most common, but there are certainly other varieties. For example, the contour of a shore may be modified by the collapse of the roof of a cave or by the action of wind as sand dunes are blown out to sea. In some instances a coast is formed by a combination of agents. A volcanic coast may, for example, be modified by coral growth or a fault coast changed by wave action.

ISLANDS

The traditional definition of an island is that it is a body of land completely surrounded by water. To this definition we should add the statement that at least part of this body of land is permanently above the high-water mark. We might add that at low tide some islands are peninsulas.

Islands range in size from tiny ledges of rock peeping above the surface of the sea to enormous landmasses measuring thousands of square kilometers in area. They fall into several groups. The name *continental islands* has been given to bodies of land that were formerly joined to continental areas. *Island arcs* are groups of islands that are strung out in long arching chains off the coasts of various continents. *Oceanic islands* have been built up by natural forces from the ocean bottom. They are usually far distant from the shores of the nearest continent.

Some islands are formed of beach material separated from the main shoreline by a shallow lagoon. These types of islands, called *barrier bars,* act as buffers between the shore and powerful ocean waves. A large stretch of barrier bars extends from the southern shore of Long Island, New York, to the Florida Keys.

Glacial deposits also contribute to the formation of islands. As ice sheets move across continental areas, they carry large amounts of loose, rocky material. This material is deposited as the ice sheet recedes, often forming islands in shallow-water areas.

CONTINENTAL ISLANDS

Continental islands represent the unsubmerged portions of the continental shelves. Some of them have resulted from the force of erosive wave action. Others have come into being as a result of the sinking of coastal highlands. Only the summits of these highlands now remain above water. Certain continental islands have been built up from the rock fragments resulting from wave erosion of coasts or from deposits in

Palau, an island group in the Pacific, east of the Philippines, includes several volcanic islands and many small coral islands. Most of the chain is surrounded by a barrier reef

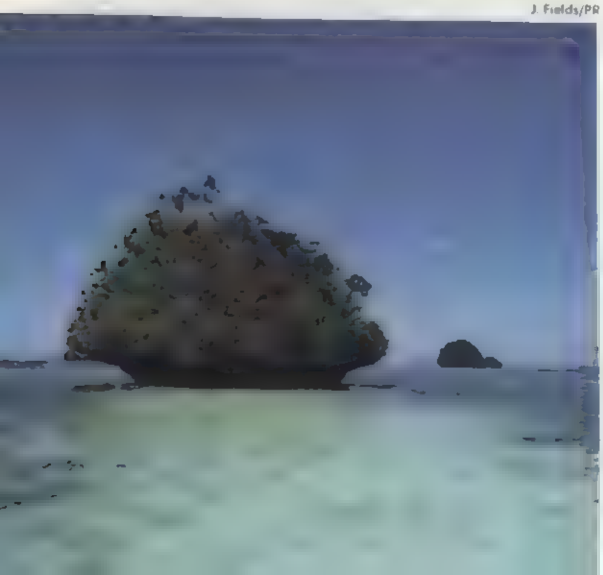
The British Isles, above, once formed part of the European mainland. This would again be the case if the level of the English Channel sank or the sea floor rose.

the form of sand bars. Still others represent portions of a growing delta at the mouth of a river, formed by sediment carried downstream.

In some cases, there may be only a shallow channel between a continent and an adjacent island that was once attached to it. The English Channel, for example, is so shallow that England would again form part of the European mainland if the level of the Channel fell a hundred meters or so, or if the seabed rose by the same amount. On the other hand, there is a deep channel of ancient origin between Africa and the continental island of Madagascar. This was probably caused by the drifting apart of Madagascar and Africa.

There are a great many examples of continental islands. Long Island, Block Island, Martha's Vineyard, and Nantucket, all lying off the North Atlantic coast, were once attached to North America. The European mainland once included a number of

J. Fields/PR



A small island—the result of volcanic and coral activity—juts from the sea and is filled with lush vegetation.

A barrier reef in Polynesia. Barrier reefs are generally low-lying, quite massive, and 100 meters or more from land.

land areas that have since become islands—Sardinia, Corsica, Novaya Zemlya, Ireland, and England, to mention only a few. The island of Madagascar at one time formed part of the African continent. The huge islands of Sri Lanka, New Guinea, Borneo, and Sumatra were all formerly attached to the continent of Asia. The island of Tasmania was once part of the great island-continent of Australia.

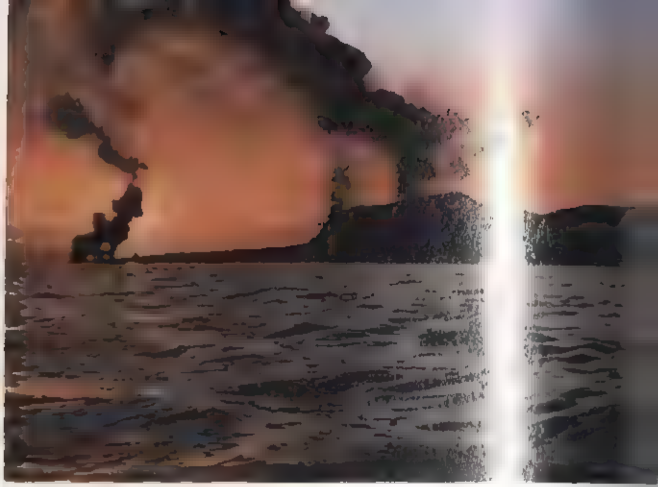
ISLAND ARCS

Island arcs, as we have seen, are curving chains of islands that extend from the coasts of various continental areas. They represent definite zones of instability in the earth's crust. Among them are some of the world's largest island groups—the Indonesian Archipelago, Japan, the Aleutians, and the West Indies.

Each island arc has an outer, convex side fronting on the open sea, and an inner, concave side, facing the nearest continent. The outer side is often quite mountainous. Off its shores and parallel to them are often found oceanic trenches—deep, narrow depressions in the ocean bed. They include some of the deepest oceanic abysses known. Along the inner side of island arcs we frequently find volcanoes, some of which are devastatingly active. Island arcs are also subject to severe earthquakes.

Curiously enough, geologists have found that certain mountain ranges, many kilometers away from the nearest sea, display some of the same features as modern island arcs. They form long, curving chains. Though now quite stable, they show signs of past volcanic activity. Here, too, are found enormous masses of sedimentary rock, originally deposited as sediments in surrounding but long vanished seas. Mountain ranges of this kind—or their remains, if they have largely disappeared—are believed by some authorities to represent the sites of former island arcs. The Alps are a good example; so are the Appalachian Mountains in North America.

According to one theory, the following series of events probably took place in the evolution of the Appalachians from an island arc to a typical mountain chain. Several hundred million years ago, there was an island arc off the eastern coast of North America. In the course of geologic ages, rock and soil were swept away by streams and were deposited on the bottom of the sea basin between the island arc and the neighboring continent. Streams of lava from the island-arc volcanoes also made their way into the basin. Ultimately the sediments and lava flows that had accumulated in the basin became huge masses of sedimentary and igneous rocks. Then the earth's crust began to buckle and heave, at first intermittently and then in a great cli-



Left: a spectacular smoke pillar heralds the birth of the island of Surtsey, off the coast of Iceland. This 1963 undersea volcanic eruption is shown in its third day. Above: the island—up from the sea—as it appeared in late 1963. This "instant island" is really the peak of a volcanic cone resting on the sea floor.

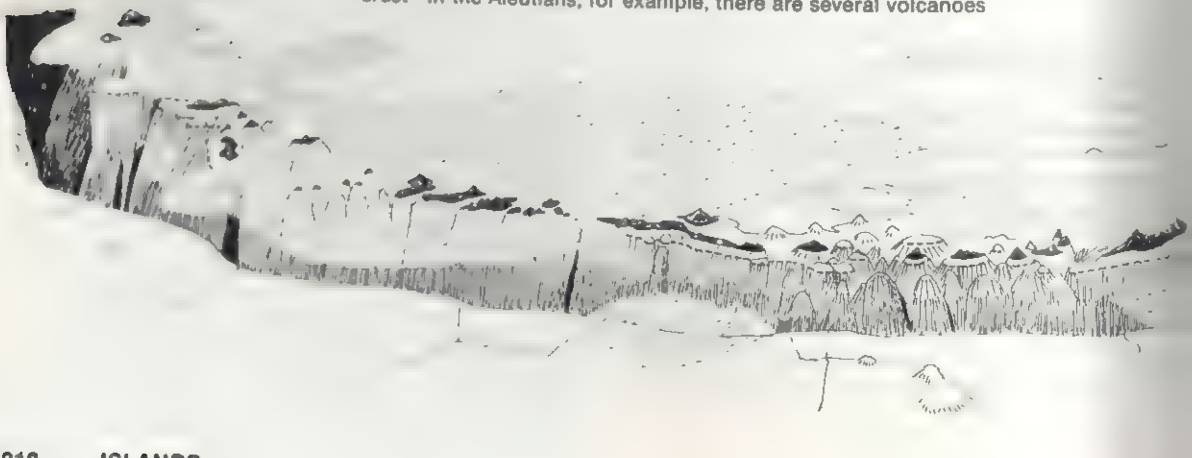
max of activity. As a result, the rocks of the area were folded and raised. The former sea basin became part of the adjacent continent, and chains of lofty mountains were formed on the newly created land. These mountains were almost entirely leveled in the course of time by the forces of erosion. However, the area was moderately uplifted again and again to form the low, rounded hills so characteristic today. Of the ancient rocks that composed the actual mass of the island arc itself, little or nothing appears to have survived.

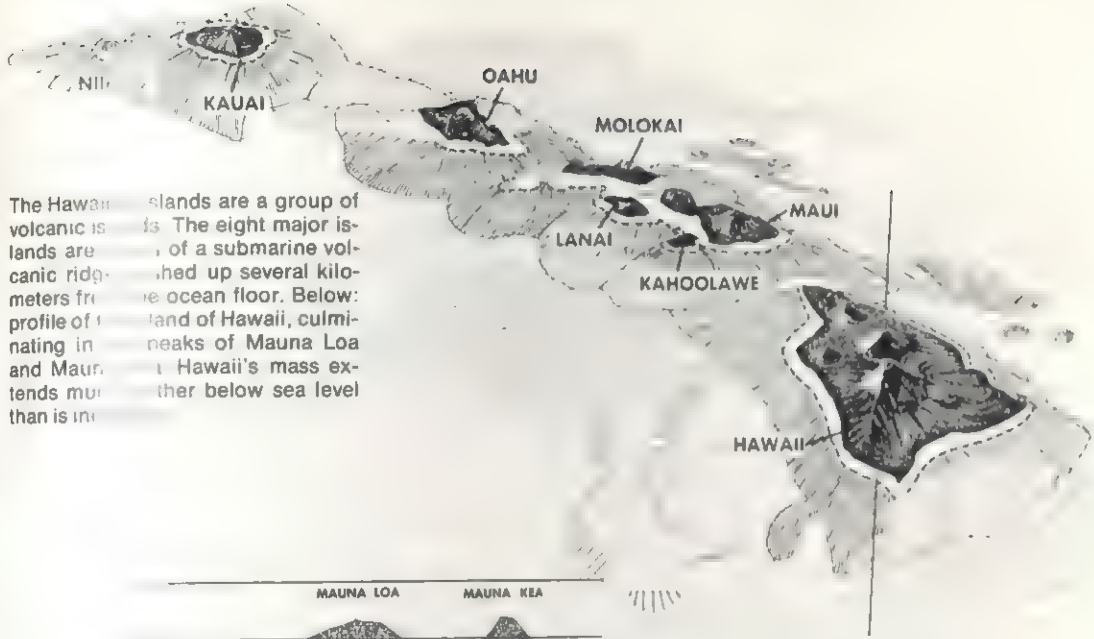
VOLCANIC ISLANDS

When a volcanic eruption takes place on the ocean floor, cinders and fra nts of igneous rock are accumulated an orm a new layer on the ocean bed. As erup-tion follows another, other layer e deposited and eventually a volca sland appears above the surface of the This island is really the peak of a vol cone that rests upon the ocean bed.

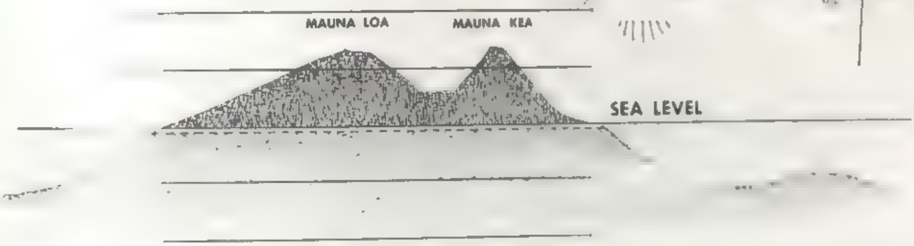
Volcanic islands are widely ersed over the face of the globe. Somet they occur singly. In other cases, t form more or less extensive chains. Th awaiian Islands, for example, consist chain of eight inhabited islands and a nu ber of rocky islets in the Pacific Ocean, about 3,200 kilometers southwest of San ancis-

The Aleutian Islands form a long island arc extending from the southw tern tip of the Alaska Peninsula Such arcs represent zones of instability in th earth's crust—in the Aleutians, for example, there are several volcanoes





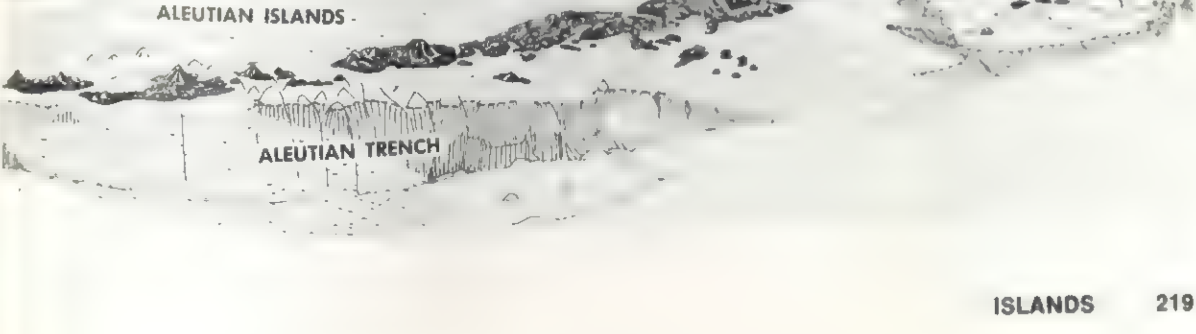
The Hawaiian islands are a group of volcanic islands. The eight major islands are tops of a submarine volcanic ridge pushed up several kilometers from the ocean floor. Below: profile of the island of Hawaii, culminating in the peaks of Mauna Loa and Mauna Kea. Hawaii's mass extends much farther below sea level than is indicated.

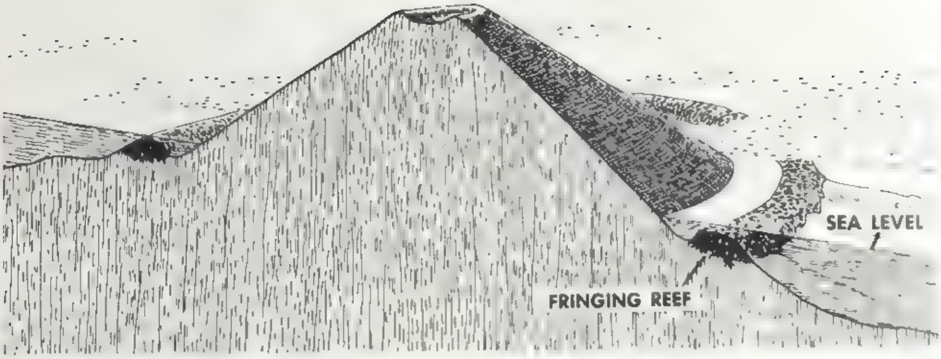


co. The larger islands represent the peaks of a submarine volcanic ridge pushed up from the ocean floor through nearly five kilometers of sea. Some of the smaller islands are coral formations. There are numerous other islands of volcanic origin in the Pacific. They include the Samoa Islands, the Marquesas, and the Galápagos groups. In the Atlantic, the Azores, Ascensión, and St. Helena, among others, are of volcanic origin.

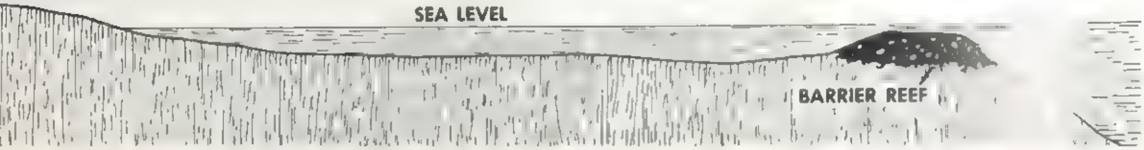
CORAL ISLANDS

The most interesting oceanic islands, perhaps, are those built up by coral polyps and certain other marine organisms. These coral islands are really reefs whose upper surface is now permanently above sea level.





The diagrams here illustrate two types of coral reefs—fringing reefs and barrier reefs. Above is a cutaway of an island with the surrounding fringing reef. Below: the profile of a landmass and a barrier reef. Barrier reefs are more massive than fringing reefs and extend farther out from the land mass.



Aitutaki, Tahiti, a coral atoll, is made up of eight islets surrounding a lagoon.

Monkmeyer

The reef-builder that we call the coral polyp is a tiny animal with a baglike body and one or more circles of little tentacles around the mouth. The animal remains attached to one place, secreting a sort of outer skeleton—a cuplike structure of calcium carbonate into which it can withdraw. There are many varieties of coral polyps.

Coral polyps multiply by successive buddings. Eventually there arises an intricate structure of polyp cups attached to a submerged rock platform not more than 100 meters below the surface of the sea. There is now a coral colony of thousands of individuals, each enclosed in its little calcium-carbonate cup. The colony keeps rising above the rock platform as new generations arise and older generations die. The skeletons of the dead polyps are buried and crushed under the growing mass. In time they are compacted together into a limestone formation, on whose upper surface new polyp generations thrive. This structure is the coral reef. It keeps rising until it reaches the surface of the sea. As the polyps cannot stand prolonged exposure to the air, they do not carry on the reef-building activities above the surface.

How can we account for the fact that a coral reef may sometimes reach a height of up to six meters above sea level, since the coral polyps cannot live out of water? Here is the generally accepted explanation. The outer edge of the reef, catching the pounding fury of the storm-driven waves, are broken off and piece after piece is hurled inward and accumulates. The coral fragments are wet with water holding calcium carbonate in solution. As the water evaporates, this limestone-to-be crystallizes. It binds the broken fragments into solid coral rock above the former surface of the reef.

Coral polyps, including those that do not form reefs, are found in all the oceans of the world. They occur as far north as the waters off Cape Cod, Massachusetts, and the Norwegian coast. However, reef-building polyps thrive only in waters that seldom go below 18° Celsius. They are restricted, therefore, to an area extending roughly from 30° north latitude to 30° south latitude. Also they flourish only to a depth of about 40 meters. Other reef-builders, including the reef-building algae called nullipores, are similarly restricted.

In spite of the limitations to which they are subjected, the reef-forming polyps have done an immense amount of building. It is estimated that the world's coral reefs of all types have a combined area of something like one million square kilometers. The debris resulting from the erosion of the reefs by ocean waves is spread over an even greater area of the ocean bottom. Reef-building polyps are abundant in the West Indies, the Red Sea, the Gulf of Mexico, the western part of the Indian Ocean, and particularly in the vast reaches of the South Pacific Ocean.

The coral reefs of the world may be divided into three classes: fringing reefs, barrier reefs, and atolls.

Fringing reefs. These are comparatively small formations that border islands and

This reef-forming coral, a stony coral, can flourish only in the presence of a symbiotic alga within its tissues. For this reason these corals grow down to a depth of less than 40 meters. They grow best where the waves break.

Tom McHugh/Photo Researchers

continental coasts. They are quite close to the shore, from which they are separated by a narrow channel of shallow water. On the seaward side, the water is deeper but it is still quite shallow. The sea floor slopes gradually. The upper surfaces of fringing reefs are exposed only at very low tide. Reefs of this type are to be found, among other places, off Mauritius, Sri Lanka, and Florida.

Barrier reefs. Like fringing reefs, they lie off continents and islands, but they are more massive and farther from land than fringing reefs. Also there is deeper water on both the seaward and the landward sides. There are various breaks in the coral barrier, and these are kept open by the tides. As a result, some of the deeper lagoons between the shore and the surrounding barrier reef are readily accessible to shipping, and they make excellent harbors. Barrier reefs are low-lying, rarely reaching a height of more than three meters. They are very narrow.

The largest barrier reef in the world is the Great Barrier Reef, which extends some 2,000 kilometers off the eastern coast of Australia. It is from 15 to 145 kilometers in width. Its distance from land ranges from 15 to 160 kilometers. The channel that is formed by this reef is generally quite shallow and in many places is exceedingly treacherous. Numerous gaps in the reef provide passage for ocean-going ships. Among these gaps are the Great Northeast Channel, Trinity Opening, and Flinders Passage. A number of islands lie between the Great Barrier Reef and the Australian coast, including the Northumberland, Cumberland, and Palm groups.

Another immense barrier reef—about 650 kilometers long—occurs off the west coast of New Caledonia, in the South Pacific Ocean.

Atolls. These formations are oceanic islands, generally found at a considerable distance from land. They are roughly circular in form and they enclose lagoons. There are often breaks in the encircling reefs. These breaks may be so extensive, indeed, that the atoll is to all intents and purposes a chain of islands. A good example is Kwajalein, in the Marshall Islands. It consists of some ninety islets surrounding the central lagoon. In other cases, there are no breaks at all in the atoll, so that the lagoon is completely shut off from the sea. Swains Island, in the American Samoa group, is this type of formation.

Seaward from the atoll, the water is usually very deep. The enclosed lagoon is shallower, though it may reach a depth of 60 meters or even more. Within it are to be found numbers of slightly submerged coral formations, called *pinnacles*, as well as an abundance of colorful marine life. Through breaks in the surrounding reef, boats, and in some cases ships, can enter the lagoon, where they find safe anchorage.

Many atolls display various forms of tropical vegetation, including coconut palms, ferns, and flowering plants. Taro, sugarcane, and other food plants thrive. Birds, including frigate birds, gannets, and terns, breed there. Land crabs and coconut crabs abound; so do rats.

The soil on which all these forms of life are dependent, directly or indirectly, is built up on atolls in various ways. The eroding attack of air, ocean waves, and rain breaks down exposed coral into fragments. Sediments and decaying organic matter are washed up onto the reef from the sea. Droppings from migrating birds fall upon it. The dead bodies of some of the migrants add to the accumulation. In time, there arises a covering of fertile soil.

The winds carry pollen and spores to atolls from distant land areas. Birds bring seeds in their crops or attached to their feathers or feet. Other seeds, such as coconuts, are carried to atolls by ocean currents and are washed ashore. Eggs of various reptiles and other animals are brought on drifting logs. By the time man arrives at the atoll, he finds an established plant life and animal life. Man introduces food plants, domestic animals, and also the rat.

Atolls are particularly abundant in the Pacific Ocean. They include the Caroline, Marshall, Gilbert, and Tuamotu island groups and many scattered islets. In the Indian Ocean, the Maldive and Laccadive islands are the most important atoll groups. Atolls are also to be found in the West Indies and the Bahamas.

THE SEA

by Joel W. Hedgpeth

As land dwellers, human beings often forget that even the mightiest continents are islands set in the midst of the even mightier ocean. The waters contained in the salt seas of the earth are so vast in extent that they stagger the imagination. They cover more than 70 per cent of the surface of the earth—three-fifths of the Northern Hemisphere. The average depth of the sea is about 3,800 meters, while the average height of the land is only 840 meters. There is three hundred times more living space available in the ocean than in the land and air put together. Everywhere in the sea one finds life: abundant near the surface; sparse at the greatest depths.

The sea has been a highway and a storehouse since early days, and the callings of the fisherman and the sailor are among the oldest known. Men went down to the sea on ships long before they learned about the composition and properties of oceanic waters and about the living things that dwell in the sea. Therefore many strange ideas arose concerning the ocean and its mysterious inhabitants. Even today we know so little about many parts of the sea that we cannot safely deny that great sea monsters of some kind exist somewhere, although we are reasonably sure that there are no huge snakes, or "sea serpents."

One of the earliest beliefs about the sea was that it was a great river, circling the known world. Beyond the great salt river there was the rim of the world, and beyond that rim, nothing. The sea was a mysterious place in those days, filled with many strange and wonderful things. However, people's desire for new riches and their curiosity about the world were stronger than the fear of the unknown. Defying the terrors of the deep, seagoing explorers set out for strange lands early in the dawn of history.

EARLY SEA EXPLORERS

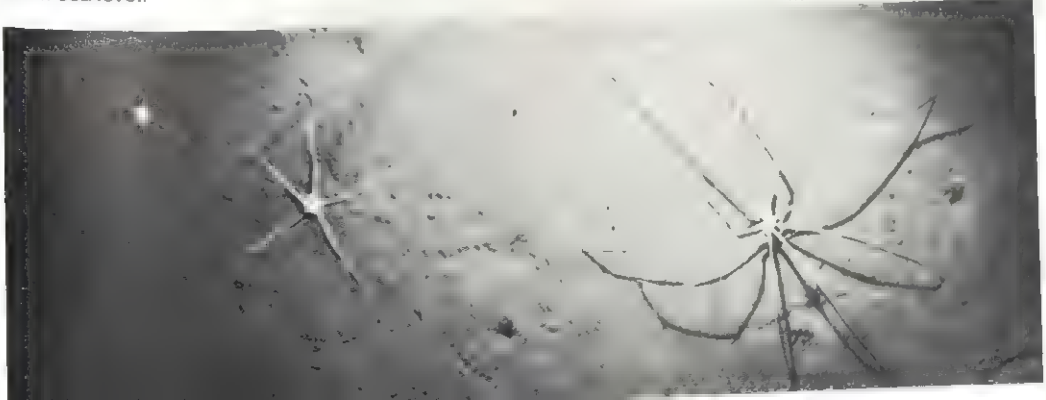
There is good evidence that many great exploring expeditions were made in the days of the Egyptians, more than three thousand years ago. In low, open boats with clumsy sails and heavy oars, Egyptian sailors voyaged from the Red Sea halfway down the coast of Africa in search of fabulous riches for the Pharaohs.

According to tradition, the greatest mariners of the ancient world were the Phoenicians, who, as the Greek historian Herodotus reports, sailed completely around Africa about 700 B.C.. It seems that the Phoenicians also sailed westward as far as the Azores and the Canaries. Perhaps they penetrated even farther out into the Atlantic Ocean.

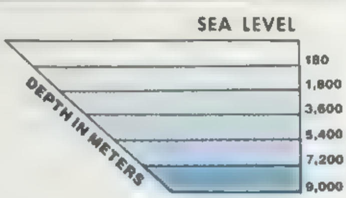
Recently, historians have begun to suspect that even greater mariners than the Phoenicians blazed the way, and that their discoveries were deliberately suppressed

Life forms are found at even great ocean depths. The two brittle stars and the large sea spider are typical bottom dwellers. Their home is over 1,800 meters below sea level.

Woods Hole Oceanographic Institution



Courtesy, U.S. Na... ...phic Office



A typical bathymetric chart, showing the depths of the sea surrounding South America. The Sandwich Trench, near the bottom of the chart, is a deep in the Atlantic Ocean

by the Phoenicians. These earlier explorers are said to have been from the island of Crete.

It was a Greek who made the first recorded voyage of exploration to the icebound waters of the Arctic Ocean. This was Pytheas, who sailed from Marseilles to England and then all the way to Iceland. About 300 B.C., Pytheas wrote a book, long since lost, about his northern travels. All we know of his voyages are a few quotations from the book in ancient writings.

For a long time, man's knowledge of the sea depended on such voyages of exploration. We cannot mention here all the expeditions that have been made since ancient times. It is an oft-told tale how the Vikings crossed the Atlantic long before Columbus; how Columbus himself defied the unknown in one of man's supreme adventures; how Magellan sailed partly around the world, and how, after his death in the Philippine Islands, his men completed the first voyage around the globe.

BEGINNINGS OF OCEANOGRAPHY

Until the time of the 17th century mariner Captain William Dampier, most sea captains were not so much interested in the sea itself as in far-off lands. Dampier, a sort of parttime pirate, had more scientific curiosity than most of his predecessors. He set down data concerning the winds and currents and marine life he encountered on his voyages. His accounts of his travels added considerably to man's knowledge of the sea.

Captain James Cook explored vast stretches of the Pacific in the course of his three great voyages in the eighteenth century. After his death, ships such as the *Beagle*, on which Charles Darwin sailed as naturalist, charted poorly known coastlines and scattered islands. In the course of time, it became apparent that such activities as these did not suffice. It was becoming necessary to learn more about the currents of the ocean and about the bottom of the sea.

The pioneer in this essential task was Matthew Fontaine Maury. As a lieutenant in the U. S. Navy, he was in charge of the Depot of Charts and Instruments, known later as the Hydrographic Office and, since 1962, as the U.S. Naval Oceanographic Office. Maury analyzed hundreds of logbooks, with their daily records of winds and currents and other conditions each day at sea, and he drew up comprehensive charts of the winds and currents. These charts proved most valuable to the captains of the remarkably swift clipper ships of the 1850s.

Maury saw the need for information about the bottom of the ocean in connection with the laying of a cable between Europe and America. Expeditions sent out on his advice began the first systematic sounding of the ocean deeps and collection of samples of the ocean bottom. With this information Maury was able to draw up a chart of the bottom of the North Atlantic Ocean, showing the route over which a cable could be laid. This was the route that was eventually adopted. Such charts of the bottom—bathymetric, or "depth-measuring," charts—are now prepared from sonic soundings. These are made by recording the time the echo from a sound emitted by an instrument in the ship's hold takes to return from the bottom of the sea.

The U.S. Civil War interrupted Maury's work. As a Virginian he decided to cast his lot with the South, and this, of course, meant the end of his remarkable career as a U. S. Naval officer. After the war he spent his last years teaching geography and geology at Virginia Military Institute. His pioneer work in oceanography was taken up by English scientists. In 1872, the year before Maury died, the steam corvette H.M.S. *Challenger* sailed from England on an oceanographic expedition. It was the first round-the-world expedition ever sent out to study the sea itself instead of seeking new lands or new sources of wealth. With the *Challenger* expedition, the twin branches of oceanography—physical oceanography and marine biology—were brought together.

STUDY OF MARINE LIFE

The beginnings of marine biology can be traced back to the renowned Greek philosopher Aristotle of the 3rd century B.C. In certain respects, he was a greater marine biologist than any who followed him, for he made many notable observations with no books to guide him and no microscope with which to see fine details. He studied chiefly the seashore animals of the Greek coast. In the words of Charles Singer, an English historian of science, Aristotle has left an "imperishable account of some of the things he has seen with his own eyes."

There was no study of seashore life comparable with that of Aristotle until almost the beginning of the nineteenth century. In the first part of that century, biologists of England and Norway made many striking contributions to man's knowledge of life in the sea. The leader in these discoveries was Edward Forbes, who classified ocean life according to the depths in which it was found. In Forbes' day, methods of dredging the great deeps had not yet been invented. Generalizing from studies he made in shallow depth, Forbes was convinced that there was no life on the bottom below 550 meters. This was an error, to be sure, but a very stimulating one, for scientists set to work to put Forbes' theory to the test. Within twenty years after his death, they had proved that such types of animals as sea stars, worms, and mollusks lived on the ocean bottom at depths of more than one and one-half kilometers. From later explorations by the Danish ship *Galathea* and the Russian ship *Vitiaz*, men came to know that such creatures occur on the bottom in the deepest parts of the ocean—the Philippine trench and the Kurile Kam-

chatka trench, more than ten kilometers beneath the surface of the sea.

The *Challenger* expedition was organized by men who were students of Forbes and were carrying out the work that he started. The results of the expedition, which added immeasurably to man's knowledge of the ocean and of the creatures that dwell there, were published in fifty huge volumes. They are still a model for contributors to the sciences of oceanography and marine biology.

THE SALTINESS OF THE SEA

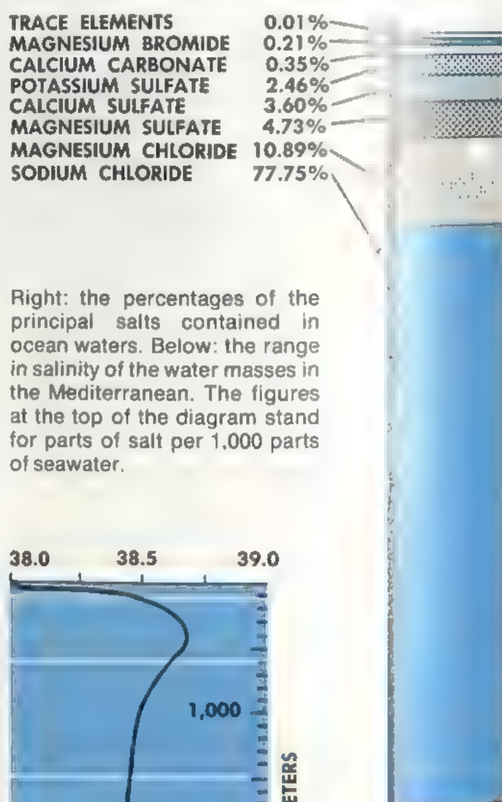
As a result of the work of oceanographers, particularly in the nineteenth and twentieth centuries, we have come to know a good deal about the waters of the sea and about its innumerable inhabitants.

One of the most striking features of the oceans is their salinity, or saltiness. When we speak of salinity, we have in mind not only common salt (sodium chloride: NaCl) but a great variety of other salts as well. These are dissolved in water as ions—electrically charged particles.

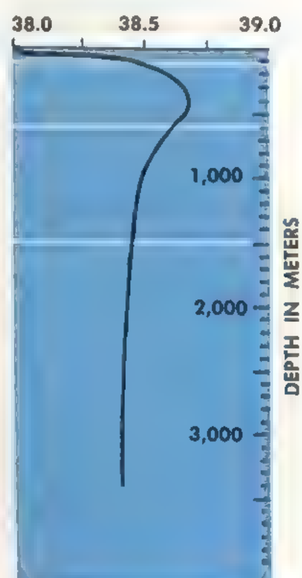
The saltiness of the sea was once a puzzling mystery to mankind. The most ingenious explanations were offered to account for the phenomenon. You may have heard the ancient tale of the salt machine that kept on grinding salt because the magic words that caused the machine to stop had been forgotten. The ship on which the machine had been installed finally sank, because of the increasing weight of the salt. Since that time, according to the tale, the magic machine has continued to grind out salt at the bottom of the sea, making all the ocean waters salty.

The generally accepted explanation of the saltiness of the sea is quite different, of course. It is based on the fact that no water that has been in contact with the earth's surface is 100 per cent pure. Rivers contain many soluble substances that have been washed out from the land. They carry these substances to the sea. Many geologists believe that a large proportion of the salts of the ocean are obtained from water that derives its heat and chemical activity from volcanic sources in the interior of the earth.

The average salinity of the ocean—the average salt content—is a little less than 35 parts of salts for every 1,000 parts of seawater. This is 3.5 per cent. The surface salinity near the shore may be considerably less. Surface salinity depends upon the ratio between evaporation and precipitation—a ratio determined by climate. In the Arctic Ocean, the huge amount of fresh water emptied by the Siberian rivers, as well as the restricted evaporation at this latitude, helps keep the salinity especially low. In partly enclosed areas, such as the Baltic, the salinity may drop below 10 parts per 1,000. In regions of scant rainfall salinities



Right: the percentages of the principal salts contained in ocean waters. Below: the range in salinity of the water masses in the Mediterranean. The figures at the top of the diagram stand for parts of salt per 1,000 parts of seawater.



Upper diagram adapted from "Oceanography, Science of the Sea," by Dr J. P. Tully, publ. by the Dept of Fisheries of Canada, left-hand diagram adapted by permission from Sverdrup, Johnson, and Fleming, "The Oceans Their Physics, Chemistry and General Biology," Prentice-Hall, Inc

in partly enclosed waters may become very high. In the lagoons of southern Texas, salinities may reach more than 100 parts per 1,000 during the summer.

The surface salinity in the equatorial regions is about 35 parts per 1,000. Abundant rainfall more than makes up for the evaporation caused by the high temperatures. Farther north and south, the salinity increases. It reaches a maximum of about 37 parts per 1,000 in the subtropical anticyclones, or horse latitudes, where evaporation exceeds precipitation. Beyond these areas the salinity again decreases, until it finally becomes lower than in the tropics.

The salinity of deep water does not show such a wide range as that of surface water, since rainfall and evaporation do not enter into the picture. Generally the salinity for deep water is between 34.5 and 35 parts per 1,000, though there are certain areas—such as the Mediterranean and Red seas—where the concentration reaches 40 parts per 1,000.

MAIN OCEAN SALTS

Common salt, or sodium chloride, is more plentiful in the sea than all the other salts put together; it accounts for nearly 80 per cent of the total. Sodium chloride plays an all-important part in living processes. It also constitutes one of man's most valuable resources.

Magnesium chloride is next in importance. The success of the process for recovering magnesium from seawater has made it possible to extract this metal in large amounts. Sulfur, an element that is extremely important in life processes, occurs in the form of several compounds with other elements.

Compounds of calcium are less plentiful, because the amount of most natural calcium compounds that can remain in solution in seawater is very small, compared to that of sodium or magnesium compounds. Calcium is extremely important, however, to the animals that use calcium carbonate or calcium phosphate in their shells or skeletons. The tremendous volume of calcium carbonate that has reached the sea in solution during past geological ages is shown by the widespread limestone formations.

Potassium compounds are still less plentiful in ocean waters. Once they have reached the sea, they may be carried down to the bottom with fine clay also brought down by the rivers. These compounds may react with minerals on the sea floor to form new minerals high in potassium. Rocks containing minerals formed in this way are sometimes used as a local source of potash the commercial name for certain potassium compounds—in fertilizer. Potassium salts crystallize out of brine only when a great amount of salt water evaporates practically to dryness. This has taken place in the Stassfurt region of Germany, in Solikamsk in the Soviet Union, and in parts of eastern New Mexico and western Texas in the United States. In all these places commercial mining of potash is carried on.

OTHER ELEMENTS IN THE SEA

Bromine is another element found in compounds in seawater. It is extracted and used in ethylene dibromide for improving gasoline. Compounds of carbon occur in seawater not only as dissolved gas—carbon dioxide and carbonate and bicarbonate ions—but also as an essential part of living organisms. After these organisms die, the carbon may return to solution in the water or it may be buried on the bottom. Under ideal conditions this buried carbonaceous material may contribute to the formation of deposits of oil or natural gas.

Boron, present as the familiar boric acid, occurs in seawater and is known to be concentrated by certain marine organisms. Silicon, next to oxygen the commonest element in the earth's crust, occurs in the form of the compound silica, or silicon dioxide. The delicately sculptured cell walls of the microscopic plants called diatoms contain silica. Among other elements found in the sea are phosphorus, iron, aluminum, barium, fluorine, iodine, arsenic, manganese, and copper.

DISSOLVED GASES

Various gases are dissolved in the oceanic waters. The principal ones are ni-

trogen, oxygen, and carbon dioxide, which are also found in the earth's atmosphere. Nitrogen accounts for 78 per cent of the gases in the atmosphere, oxygen for 21 per cent and carbon dioxide for 0.03 per cent. The percentages are different in salt water. The ratio of nitrogen to the other gases is somewhat smaller, coming to about 64 per cent. It is thought that nitrogen-fixing bacteria in the sea may use this gas in the production of nitrates, which are essential to life.

About 34 per cent of the gases in solution in the sea consists of oxygen. This gas is absorbed by marine organisms in the process of respiration and is as vital to them as is the water in which they live. The proportion of carbon dioxide to other gases in the ocean is about 50 times greater than in the earth's atmosphere. Yet it is very small, amounting to only about 1.6 per cent by weight. Carbon dioxide plays a vital part in the food-manufacturing process of photosynthesis that goes on in various types of marine plants.

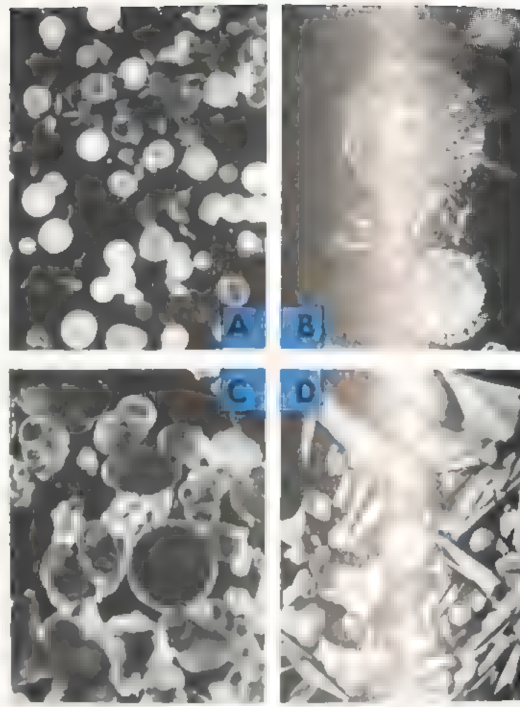
ORGANIC SUBSTANCES IN THE SEA

Various organic substances—the remains of marine plants and animals—are in solution or suspension in the sea. According to one estimate, the dissolved organic substance is equal to 300 times the amount of living organic material in the sea at any one time. Included in this material are byproducts of metabolism, including vitamins, which are suspected of having a great influence on the populations of organisms in the sea. Changes in the minute concentrations of these substances in seawater may set in motion the train of events bringing about a *red tide*—an outburst of poisonous microorganisms that kills fishes and other forms of marine life.

While the concentration of inorganic salts may be fairly uniform throughout the oceans, the dissolved organic material varies greatly from place to place. The biological properties of seawater may be strikingly different at two places less than two kilometers apart.

OCEAN BOTTOM DEPOSITS

The ocean bottom is often covered



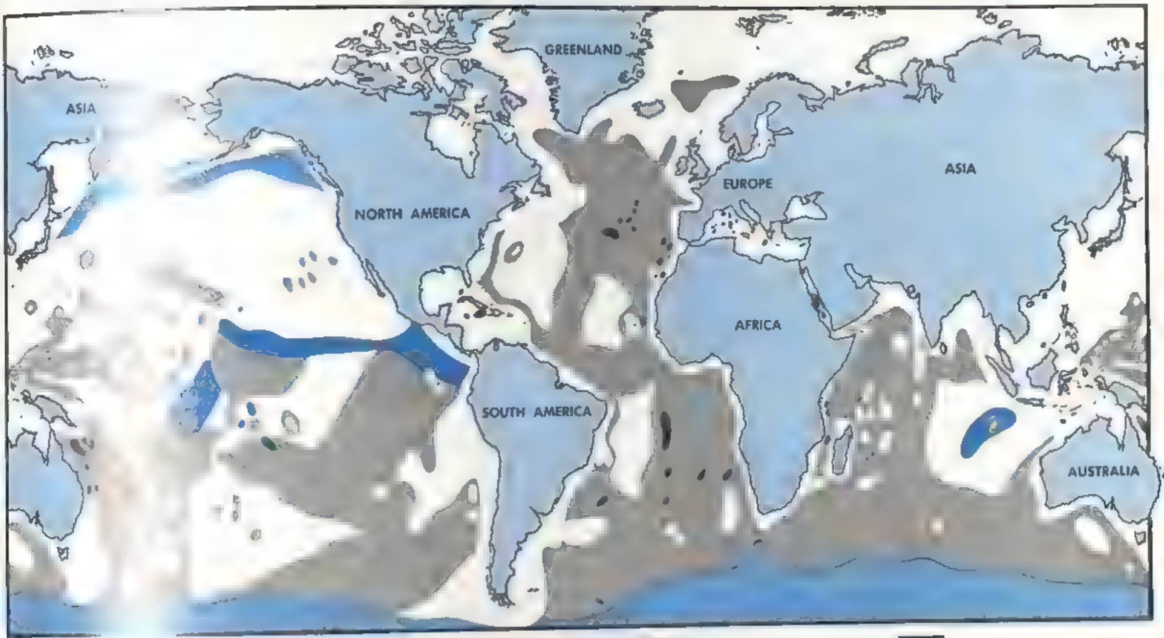
A, B and C: Douglas P. Wilson, D: materials furnished by ... Naval Oceanographic Office, photo by Atco Scientific Photography

Four types of oozes—organic deposits found on the ocean bottom. A: diatom ooze; B: radiolarian ooze; C: globigerina ooze; D: pteropod ooze

with the hard remains of animals and plants. The deposits near the coasts consist mostly of quartz and other mineral matter carried from the land by rivers or brought to the sea because of the pounding action of waves upon coastal rocks. Somewhat farther from the coast, the ocean bottom is covered not only with materials from the land but also with the remains of crustaceans, mollusks, tube worms, and the like. Finally, in the areas beyond the direct influence of the land, we find *pelagic*, or deep-sea, *deposits*.

These include four kinds of *oozes*, or deposits, which are of organic origin and which are named for the materials most often found in them. They are called diatom, globigerina, radiolarian, and pteropod oozes.

The diatoms, which predominate in *diatom ooze*, are tiny plants that have siliceous cases, or shells. They form the food of many animals. Their cases, however, being indigestible, pass through the alimen-



Map showi ... distribution of the four kinds of oozes in the world's oceans. Note that t... obigerina ooze is widely distributed, while the pteropod ooze is least distrib...ted

tary tract of the animals that feed on them and finally drop to the ocean floor. Diatom ooze is found in the cold regions of the Antarctic. It is also fairly abundant in the Pacific.

In *globigerina ooze*, the calcareous shells of the one-celled animal *Globigerina bulloides* predominate. About two thirds of the ocean bed of the Atlantic is covered by globigerina ooze, which is also found in many other areas.

Radiolarian ooze consists of a foundation of red clay, in which the remains of radiolarian shells are mixed. The radiolarians are protozoans with siliceous shells; they are larger than most protozoans. Radiolarian ooze occurs in the tropics in various areas of the Pacific and Indian oceans.

The mollusks known as pteropods form the fourth type of ooze—*pteropod ooze*. The pteropods, which have shells of many different shapes, can usually be seen by the unaided eye. Pteropod ooze is generally found in tropical areas.

The pelagic deposits include red clay. This is particularly conspicuous at great depths. Some of the red clay is of volcanic origin: it is derived from submarine volcanoes and from terrestrial volcanic dust that has been borne to the sea. Mixed with such materials are various others, including rock fragments carried by icebergs. Red clay makes up more than half the ocean bottom of the Pacific.

TEMPERATURE, DENSITY, AND PRESSURE

Surface temperatures in the oceans are highest in the tropics or low latitudes and decrease to the north and south. The belt of highest temperature is known as the *heat equator*. In general, it is somewhat north of the geographic equator. This is due chiefly to the fact that the ratio of water to land is greater in the Southern Hemisphere than in the Northern and that this difference affects the general atmospheric circulation. Besides, the Southern Hemisphere undergoes

The parrot fish (upper) and the hogfish (lower). A brief examination of the heads of these two nekton will explain the origin of the names

d of Florida

the influence of the vast Antarctic icecap. The temperature of seawater varies from 0° Celsius, or slightly below, in high latitudes to about 28° Celsius near the surface at the heat equator.

We all know that the ocean water is denser than fresh water. When we speak of the density of seawater, we generally have in mind its specific gravity—that is, its weight compared to that of an equal volume of pure water at 4° Celsius and at atmospheric pressure. The specific gravity of seawater whose salinity is 35 parts per 1,000 is about 1.028 at 0° Celsius. It is less at higher temperatures and greater at lower temperatures. The difference in density between seawater and fresh water is shown in various ways. For example, the eggs of many fishes of the sea float at the surface, while the eggs of almost all freshwater fishes sink to the bottom.

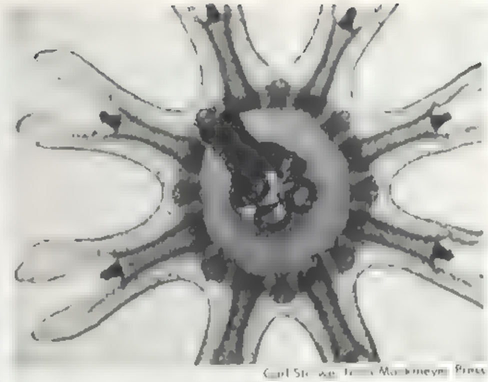
At the surface of the sea, the pressure in one atmosphere, or about 1 kilogram per square centimeter. It increases by one atmosphere for every 10 meters of depth, so that even at comparatively moderate depths the pressure is very great—more than 150 atmospheres at a depth of 1,500 meters. Of course such a pressure range is far greater than on earth, where the highest pressure is only one atmosphere at sea level.

MOVEMENT OF OCEAN WATERS

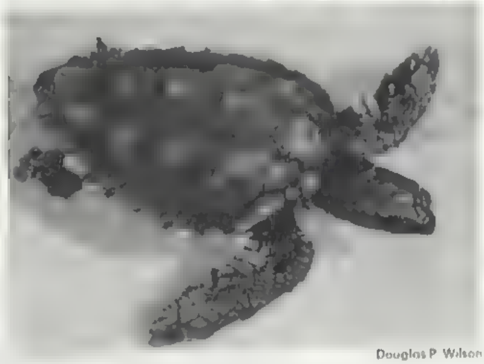
The waters of the ocean are never still. There is a constant succession of waves and tides. There are currents at and below the surface. The water set in motion in the form of waves and tides oscillates, or swings back and forth, but does not move appreciably from one place to another. But when currents arise and a system of circulation is set up, great masses of water are set in motion, and they may travel for thousands of kilometers.

Ocean currents are due to a variety of factors. For one thing the density of the water at the surface may be increased because of evaporation, cooling, or the formation of ice, which leaves the water more saline.

Douglas P. Wilson



Carl Struwe, from Monkmeyer Press



Douglas P. Wilson

Benthos, plankton, and nekton. Left: benthic fan worms. Right, top: a planktonic young jellyfish belonging to the genus *Ephyra*. Right, bottom: a loggerhead turtle—nektonic and quite carnivorous.

The increase in density causes the surface water to sink to the deeper part of the ocean. At the same time the lighter waters in these deeper areas are lifted to the surface. When the falling waters reach an area of equal concentration or temperature or when the rising waters reach the surface, they begin to spread out horizontally. The movement of ocean water is also affected by various external forces. Strong winds drive the surface layer. The level of the sea rises and falls in various areas because of variations in atmospheric pressure. The rotation of the earth causes currents to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

The surface currents and drifts and the deep flows at a considerable distance below the surface make up well-defined systems of circulation in the different oceans of the world.

LIFE IN THE SEA

The sea is the home of countless forms of life—animal life and plant life—which are affected in varying degrees by salinity, temperature, density, pressure, and current flow. The living organisms of the sea fall into three main groups: benthos, nekton, and plankton.

Benthos. The name "benthos" comes from the Greek for "depth of the sea." It is applied to animals and plants, among other things, that live out their lives fixed in one spot, after an early period in which they can swim about. Among these fixed organisms are barnacles and oysters and the marine plants known as kelps. The term "benthos" is also used to refer to such animals as starfish that creep slowly along the ocean bottom, crabs that scurry across it, and clams and worms that burrow into its sand or mud.

Nekton. The animals included in the nekton (Greek for "swimming") are at least fairly strong swimmers. They are not borne along by the currents of the sea. The nektonic organisms include vast populations of fishes: sharks, rays, salmonlike fishes, herringlike fishes, mackerellike fishes, eels, and countless other varieties. Whales, seals, and marine turtles are included among the nekton, as are squids and certain shrimps.

Plankton. By far the greatest bulk of living things in the sea falls into the plankton (Greek for "wandering") group. This names characterizes the countless marine plants and animals that are carried along by the currents. There are a few fairly large forms of plankton, such as sargassum and jellyfish, but most organisms of the plankton are very small, ranging from the copepods, which are barely visible, to the microscopic plant forms known as diatoms and bacteria. Among the animal representatives of the plankton are the larvae of such forms as snails, oysters, worms, and fish, which as adults are grouped with the benthos or nekton.

RESOURCE STOREHOUSE

The animals and plants of the sea constitute a vast resource from which man derives food, fertilizers for cultivated plants, and materials for industries. These riches of the sea may some day be our last hope of survival. We are destroying the land—its fertile topsoil and its forest cover—faster than we are replacing or conserving it. Fortunately, we cannot destroy the resources of the sea so easily—for one thing, because it is not so subject to our destructive activities as is the land.

Yet we have made certain inroads upon the vast populations of fishes and other animals that dwell in the sea. We have almost exterminated several kinds of whales, and we have at times reduced the numbers of such fishes as cod and herring. Thoughtful people have recognized the necessity of conserving the vast resources of the sea for future generations. However, there are certain difficulties in the way of such a program. For one thing, we still do not know enough about the environmental factors involved in the reproduction and growth of fishes and their often extensive migrations. Besides, even if one country establishes wise regulations for the conservation of fish stocks, the fishes, which know no boundaries, may make their way to waters administered by nations that have inadequate regulations.

In recent years, a new threat has been posed to the continued well-being of living things in the sea. This threat is the pollution of oceanic waters by radioactive fallout, as well as by radioactive wastes dumped in the sea. At the present time, this pollution is very slight. However, if atomic-power plants increase in number in the future as greatly as is expected, an increase in the amount of radioactive wastes dumped in ocean waters will more than likely affect life. Because so many marine animals feed by concentrating very fine material, it is possible for them also to concentrate radioactive material of potential harm to themselves and to man.

Obviously, cooperative action among the nations of the world is required. Several international agencies are devoted today to the study and conservation of marine life. An International Whaling Commission in London governs the catching of whales. The United States, Canada, and certain European countries set up several commissions to study and conserve the fisheries of the North Atlantic. A fishery section in the U.N. Food and Agriculture Organization (FAO) helps nations to protect and develop their fisheries.

Starting in 1973 the United Nations sponsored a series of Law of the Sea conferences. Representatives from more than 140 nations met to try to develop a "law of the sea," dealing with the exploitation of mineral wealth in the seabed, fishing rights, the widths of territorial waters, environmental pollution, freedom of scientific research, and rules of passage in narrow sea lanes. Conflicts between developed and developing nations and between maritime and landlocked countries complicated the issues. However, treaties setting standards for the use of the sea are being formulated.

Steve Lissau

WAVES

by Walter Munk

The waters of the sea are never at rest. There is always wave motion of some kind. Sometimes the waves form comparatively regular patterns. At other times their motion seems utterly chaotic. They may be alarmingly high. They may be so low that the sea shows only an almost imperceptible ripple. Most wave motion is brought about by the action of the winds. Certain waves are caused by submarine earthquakes.

Whatever its cause, a wave represents a disturbance of some kind. The result of the disturbance is not a steady forward motion of the water but more nearly an up-and-down movement. Generally speaking, each water particle rises and falls, moving forward and backward. If you have ever watched gulls resting on a wind-driven sea, you will recall that they remained in about the same place while one wave after another swept by.

You can show that water motion and wave motion are not one and the same thing by a very simple experiment. First fill a bathtub with water. You will be able to produce miniature waves by blowing on the water at one end of the tub. Put a piece of tissue paper about 25 centimeters or so

from the place where you blow. As your breath sets waves traveling along the surface of the water, the tissue paper will bob up and down, back and forth. It will not be carried to the far end of the tub.

The apparent forward motion of water as waves sweep over the surface of the sea is an optical illusion. It is no more real than the apparent forward movement produced when a wheat field undulates in the breeze. What happens in either case is that the disturbance caused by the wind is transmitted from one area to the next. In other words, it is the wave pattern and not the water that moves forward.

The highest point of the water in a wave is called the *crest*. The lowest point is called the *trough*. The distance from one crest to the next is known as the *wave length*. The height of a wave of water is equal to the vertical distance between the crest and the trough. The time it takes a wave to pass from one crest to the next crest is called its *period*.

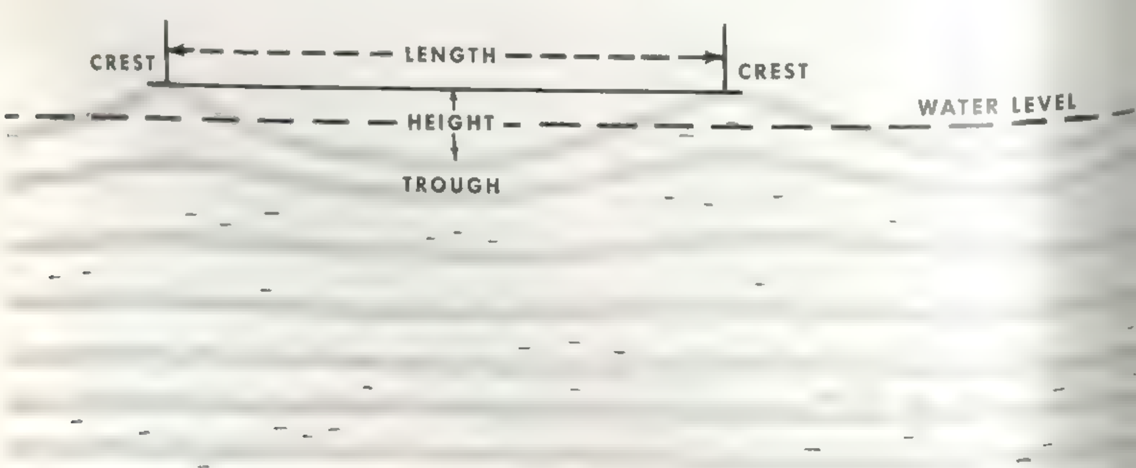
The waves of the sea are sometimes called *surface waves*. They disturb only a relatively shallow surface layer of water. Another experiment in your bathtub "laboratory" will show that this is so. Set some tissue paper about three centimeters below the surface and then blow upon the water as before. Instead of bobbing up and down, the tissue paper will not be noticeably disturbed as the waves pass over it.

At a depth of one wave length, the wave motion is only a few per cent of what it is at the surface. That is why submarines that have submerged 30 meters or more are not affected by wave motion even during a heavy storm. This has made it possible for scientists to make accurate measurements of the force of gravity at sea. It is important that the instrument used for this purpose should be shaken as little as possible. Investigators, therefore, make the required measurements in a submerged submarine.

SOME VERY HIGH WAVES

There has been a good deal of disagreement about the maximum height of waves, chiefly because it is difficult to make the necessary calculations during a violent storm. The maximum height of waves from trough to crest in most oceans is about 12 meters. In the area of the prevailing westerlies of the Antarctic Ocean, waves as high as 15 meters have been observed quite often.

Occasionally even greater heights have been reported. The British ship *Majestic* was caught in a hurricane in the North Atlantic in December 1922. One of the officers reported that for a time the waves were more than 20 meters high, on the average. Now and then they reached a height of about 30 meters. An even greater height was reported by the *U.S.S. Ramapo*. On February 6, 1933, a wave astern of the ship



rose to about the level of the crow's nest on the mainmast. At the time, the *Ramapo* was in the trough of the wave, on a more or less even keel. A simple calculation showed that this monstrous wave was 34 meters high.

Certain observers claim to have seen waves 90 to 120 meters high. Such estimates are exaggerated. Even the extreme heights noted by the observers on the *Majestic* and *Ramapo* represent exceptional ca

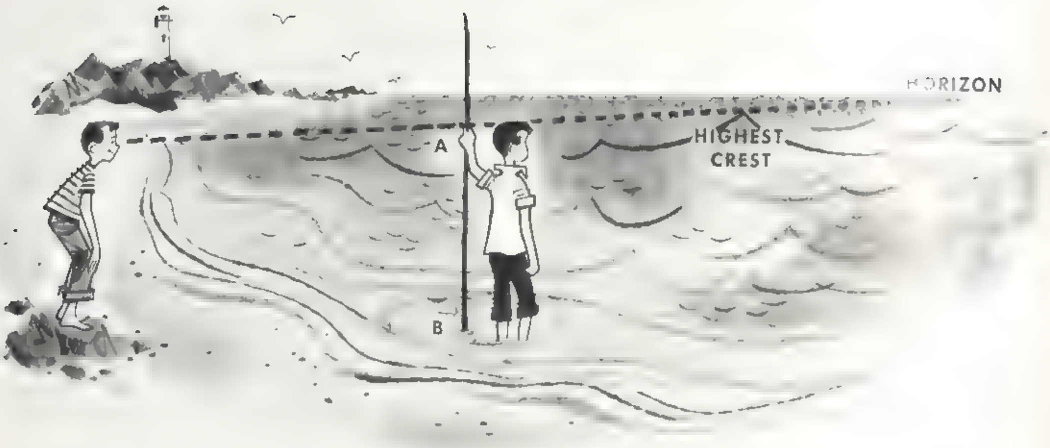
MEASURING WAVES

You can estimate the height of waves offshore by a very simple method. Stand at the water's edge on a beach and note the highest and the lowest position of the water line for three or four waves. Find the midpoint between the highest and lowest position. Drive a tall stick in the sand at that point or have one of your friends hold the stick there. Go back a short distance from the water's edge. Sight along different points on the stick until you find one at which the crests of the highest waves will line up with the horizon. The diagram given on page 236 shows how it is done. The distance AB in the diagram represents the height of the crest above the mean sea level. The total wave height (crest to trough) is almost twice this value. Of course the position of the sighting stake will vary with the stage of the tide.


U.S. Coast Guard Official Photo

An ocean weather station battling very high waves during a storm in the North Atlantic Ocean. It is difficult to calculate wave height during a storm, but the maximum height in most oceans is thought to be about 12 meters.

Another important thing to measure is the wave period. This can be done by making use of some fixed offshore object, such as a rock or a pier pile. Wait until a few large waves start rolling in. Note the exact time when each of two successive wave crests passes the rock or pile. The amount of time that has elapsed represents the wave period. Using the same landmark,



How to estimate the height of waves by means of a stick driven into the sand. Details are given in the text.

make several other estimates of wave periods. Then average the different figures. In this way you will be able to obtain a truly representative value.

If you are to spend some time at a beach, you will find it interesting to make daily observations of wave height and period, and to keep track of your measurements. You will note significant changes from day to day, and from season to season. Wave height will range from about half of a meter to many meters. Wave periods along an exposed coast will range from five seconds to fifteen seconds. There will be important differences between the results obtained, say, on a beach in Maine and on a beach in Florida. Wave heights and periods will differ even on two beaches only a few kilometers apart.

LIFE HISTORY OF A WAVE

To show how these differences arise, let us consider the life history of a typical wave. A heavy storm is forming over the Aleutians, a chain of islands in the North Pacific Ocean. Winds of 80 kilometers an hour are reported blowing from the northwest to the southeast, over a stretch of water 1,500 kilometers long. This water area, on which waves are being generated, is called the *fetch*.

On the upwind side of the fetch (the northwest end), the waves are relatively short and low. As they travel down the fetch, driven by the wind, they become higher. By the time they have reached the downwind end, some have attained heights of six to ten meters. The most prominent waves present are 90 meters long and have periods of about seven seconds. On the second day of the storm, the waves on the downwind end will be somewhat higher than on the first day. Thereafter they do not become much higher, even if the storm persists in the same area. A more complicated situation arises when the storm moves slowly from west to east along the Aleutian island chain.

When the waves reach the end of the fetch, they do not stop or disappear. Instead, they continue to travel outward from the fetch. From now on the waves become lower as they move on. The shorter waves decrease in height rather quickly, and may travel no more than 150 kilometers. The very longest waves can move all the way

from one end of the ocean to the other without losing much height.

The waves become lower and longer the farther they move from the storm area. By the time they reach Seattle, Washington, their height is five meters, their period ten seconds. At Los Angeles, California, which is about twice as far from the storm, the waves are three meters high and have a period of twelve seconds.

DETERMINING WHERE WAVES COME FROM

You can tell, roughly, whether the wind area from which waves come is nearby or far away and whether the winds are strong or weak. Use the following table:

High waves of short period are produced by strong winds nearby.

High waves of long period are produced by very strong winds far away.

Low waves of short period are produced by weak winds nearby.

Low waves of long period are produced by moderate winds far away.

If waves from one storm system are dominant, this simple method of analysis will give useful information.

It will not serve if two separate storm systems have generated waves of comparable height. There are ways of measuring the periods of two such wave trains. This is a complicated process, however, and could not be employed by the average amateur observer.

In La Jolla, California, waves from Aleutian storms come in most of the time during the winter months. In the summer, the heavy waves come from the south, from storms as much as eight thousand kilometers away. These storms travel more than a week before they reach La Jolla. They are generated in the "roaring forties," a belt of strong winds in the Southern Hemisphere.

MANY IRREGULARITIES

The more one studies waves, the more one realizes how irregular they are. High waves are followed by low waves, and the changes involved are often considerable. In one case I recorded waves that increased or decreased in height by one half from one ten-minute interval to the next. There are various other irregularities. If you sight along a single wave crest, you will note that it peters out in a sideways direction before you can sight very far.

The complexity of the sea surface is due to the fact that *wave trains* from many different sources pass over it. You can illustrate the principle involved by another bathtub experiment. Let a single large drop hit the water surface. Note the circular waves spreading in all directions. Now let two drops fall on the surface about 30 centimeters apart and as nearly at the same time as possible. The circular wave trains from the two drops will pass through each other. Each train will spread as if the other one were not there. Wave trains from two storms, or even three or four storms, can pass through one another in this way.

What we see at a given place, therefore, is the simultaneous movement of wave trains from many source regions. These may be trains from different storms, or from different parts of the same storm. If the waves are derived from the various parts of a distant storm, the spread of the directions from which they come is small. Such waves are comparatively regular in appearance. If they come from different parts of a nearby storm, they will reach a given spot from many different directions. The sea surface will then be far more irregular. If a person happens to be in the middle of a storm area, the waves come in from all directions. The picture is too confused to be described in words.

FORECASTING OCEAN WAVES

From what we have said so far, it is clear that winds—present and past, local and distant—pretty well determine local wave conditions. If we know about the winds, it should be possible to predict the nature of the waves. This is the basis of a method of wave forecasting that was developed during the 1940s. A set of weather

maps is consulted. All the important storm fetches are located. Then the expected waves for each fetch are computed. The dimensions of the waves in each case will depend on the wind speed, the duration of the storm, the length of the fetch, the distance of the fetch, and various other features.

The forecasting of waves has now become far more accurate. It is now possible to predict not only the height and period of waves, but also the range of variations. Such forecasts have proved extremely useful in offshore oil drilling. They can be used in other ways. For example, if wave conditions have been properly predicted, one can calculate how much a ship will roll at a given time. One can tell how much it will pitch and how much it will be slowed down by a rough sea.

At present all ocean travel is along the shortest routes—the so-called great circle routes. There is no reason why ships should not select the fastest or most comfortable route by consulting wave forecasts. It may be possible to reduce the travel time of a ship by 20 per cent by selecting a route based on predicted wave conditions.

Most waves are generated by winds at sea. As waves move away from their place of origin, they become lower, rounded, and more symmetrical. An entire train of these waves, shown here, is referred to as *swell*. Individual waves are called *swells*.

Steve Lissau

WAVES IN SHALLOW WATER

When waves travel into shallow water—say, less than 15 to 30 meters deep—a startling transformation takes place. The waves start turning, so that crests are more nearly parallel to the shore. Wave lengths shorten. The waves become steeper. By the time they reach water that is about as deep as they are high, they topple over and break. The zone between the outermost breakers and the shore line is known as the *surf zone*.

In the deep sea, wave velocity is independent of depth. In shallow water, however, velocity decreases as the depth decreases. Suppose a wave crest comes at an angle toward a straight beach. The part of the wave crest that is still in deep water moves at top velocity, but the part in shallow water is slowed down. This causes the wave to turn so that it will be more nearly parallel to the shore. Slowing down of the wave crests in shallow water causes the crests to bunch up. That is why the waves become steeper. Waves will bend completely around a headland. Since the crests will have to stretch, the wave height will be reduced in this case.

The breaking of waves is not yet clearly understood. Probably this is what happens. In the open sea the rate of movement of surface water is very slow compared to the velocity of the crest. As the water becomes shallower, the water velocity begins to catch up with the crest velocity. Once it exceeds this velocity, the water will rush ahead of the crest and the wave will break.

Large breaking waves are dangerous because of the tremendous force they exert. Occasionally they toss rocks weighing many metric tons high up on beaches. No ship that has been driven in the surf can withstand the force of breaking waves indefinitely.

SPREADING OIL ON TROUBLED WATERS

It was once customary for ships in trouble on heavy seas to pump oil on the water. They did this to calm the waves, so as to make rescue operations easier. Oil spread on the water forms a film about a

molecule thick. This film resists the stretching and compressing that takes place as a wave passes over a given area. As a result the waves lose amplitude. Only waves less than a meter long are affected by such an oil film. Dangerous waves are not appreciably reduced in height.

The spreading of oil may have more important effects. When the wind speed over the sea exceeds 22 kilometers per hour, the short waves that are present steepen and break, forming *whitecaps*. If oil is applied in such cases, small corrugations on the sea surface are smoothed out. This makes it more difficult for the wind to "grip" the water, and to form whitecaps. Whitecaps play an important role in oxygenating ocean waters. A decrease in their formation will result in a decrease in the amount of dissolved oxygen present in the water. This, in turn, will affect the life forms present in the ocean.

INTERNAL WAVES AND SEICHE

Waves generated by the wind are only one of several kinds occurring in bodies of water. An *internal wave* may occur when a difference in density exists in a vertical section of water. This can happen where water masses with different salt contents come into contact. The waves generated by this means are slower moving than wind-generated waves, but they usually have a greater wave height.

Stationary waves, also called *standing waves*, or *seiche*, can occur in enclosed or

Morton Beebe and Associates

Right: the energy of a wave is seen here as it breaks against the rock, which will be slowly eroded by the endless pounding of the sea. Bottom: a concave, plunging wave—the type popular with surfers—is produced when the sea bottom near a beach slopes quite steeply.

Steve Lissau

Steve Lissau

Different waves pass through one another off this beach in Hawaii. In the open seas, such intersections may not have any noticeable effects on the waves.

semi-enclosed bodies of water such as lakes or bays. These waves may result from storms or from sudden disturbances in the water, or in the atmosphere. The general motion of a seiche is like that of a pan of water that has been tilted and then righted.

TIDAL WAVES

Certain violent ocean waves are caused by earthquakes or by volcanic eruptions. The waves may be caused by sudden dislocations in the sea bottom, or by submarine landslides. Both dislocations and landslides are known to occur during earthquakes. The waves that result are popularly known as *tidal waves*. They really have nothing to do with the tides, which are brought about by the gravitational attraction between the earth, moon, and sun. Experts prefer to call the waves *seismic waves* or *tsunamis*.

Tidal waves can travel for great distances at great velocities. In the open sea they are perhaps one-third meter high and a hundred meters long, and cannot be observed from ships. But on coming toward shore, they are greatly amplified. In bays and harbors that are properly "tuned" to these waves, the water may rise ten meters or more.

Tidal waves will strike the shore with truly devastating force. Ships at anchor may be swept far inland, and whole villages may be destroyed. In November 1952 a tidal wave generated by an earthquake off Kamchatka in northeastern Asia caused damage on many Pacific islands. In 1883 a 30-meter high tidal wave generated by a volcanic eruption at Krakatoa, Indonesia, destroyed almost 300 villages and killed more than 350,000 people. A huge tidal wave is even thought to have been at least partly responsible for the decline of an entire civilization—that of the Minoans on Crete in the fifteenth century B.C.

The period of tidal waves is very long—from fifteen to forty-five minutes. As a typical wave reaches the shore, parts of the sea bottom that are ordinarily submerged are suddenly laid bare, as if there were an enormously low tide. The natural reaction of people is to rush down toward the beach and explore this area that has never been visible to them before. If anything of this kind should ever happen while you are on the beach, restrain your curiosity and run as fast as you can toward higher ground. Because the period and wave length of a tidal wave are so great, the chances are very good that you would have enough time to reach a place of safety.

The speed of tidal waves in the open sea is about 800 kilometers an hour. Therefore, there might be an interval of six hours between the time an earthquake is noted, by means of a seismograph, and the time the tidal wave arrives. The United States' National Ocean Survey has organized a warning system that makes use of this time lag. Whenever a severe earthquake somewhere in the Pacific is reported, the nearest tide gauge station is alerted. In most cases the earthquake does not cause appreciable tidal waves. This is apparent from the tide gauge record. If threatening tidal waves have been formed, warnings are flashed ahead to areas that have proven vulnerable to these waves on past occasions.

New Brunswick Dept of Tourism

New Brunswick Dept of Tourism

High and low tides are easily distinguished in these photographs of Dark Harbor, New Brunswick, Canada. Boats can come and go only during high tide.

TIDES

by Bart J. Bok

The periodic rise and fall of the sea in the rhythmic pattern that we call the tides is among the most striking of natural phenomena. People became aware of tides and marveled at them long before they had the least idea of what caused them. The ancient Chinese attributed them to the respiration of a huge earth monster. According to the Scandinavian sagas, Thor, the god of aerial forces, produced tides as he alternately raised the waters of the sea by blowing upon them and then let them fall back again.

Though the mystery of the tides has not been completely solved, we now have a good idea of how they arise. We can measure them quite accurately. We can predict the time of their ebb and flow. Yet the tides still represent, as in ages past, a force with which men in various parts of the world must always reckon. A big ship in harbor must often wait for calm water to approach its pier. Otherwise strong tidal currents might cause a crash. Where there is a great range between high and low tide, as in the Bay of Fundy off the coast of Nova Scotia, all port activities may have to be practically suspended at intervals so that vessels may not be stranded in low water. In certain cases, tides advance so rapidly and with such force that it is quite literally a matter of life and death to know when high tide is to be expected.

THE MOON'S PULL

The ocean tides are brought about by the gravitational attraction between the earth and two heavenly bodies—the moon and the sun. The crust of the earth is also affected by this attraction, but its movement is so slight that special instruments must be used to detect it. The other planets

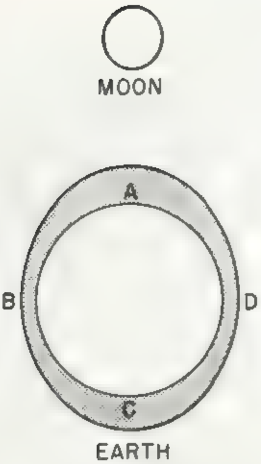


Fig. 1. The gravitational attraction between the moon and the earth's oceans and lithosphere results in the tides.

in our solar system and the stars and all the other objects in the skies also attract the earth and are attracted by it. But these objects are either too small or too far off to have any appreciable influence on the waters of the sea.

The tide-raising effect of the sun is only about 0.46 times that of the moon, in spite of the fact that the mass of the sun is about 28,000,000 times greater. According to Newton's law of universal gravitation, the force of attraction that various bodies have for one another is directly proportional to the product of their masses, but inversely proportional to the square of the distance between them. The sun is almost 150,000,000 kilometers from the earth. The moon, our nearest neighbor in space, is only about 385,000 kilometers distant. The smaller distance between the moon and the earth more than makes up for the greater mass of the sun.

Hence the ocean waters respond particularly to the moon's gravitational pull. In Figure 1 we assume that water completely covers the face of the earth. When the moon is directly over A, its attraction will cause water to pile up toward A and a *high tide*, or *flood tide*, will be produced. As water is drawn toward A from other areas, the water level will be lowered at B and D, and it will be *low tide*, or *ebb tide* at those points.

At the same time there will be a piling up of water on the other side of the earth, toward C. According to a widely held theory, the reason for this is that the attraction of the moon for the earth's lithosphere, or solid part, is greater than it is for the water at C, which has less mass and is farther away. The lithosphere is drawn toward the moon, leaving the water at C farther from the earth's center.

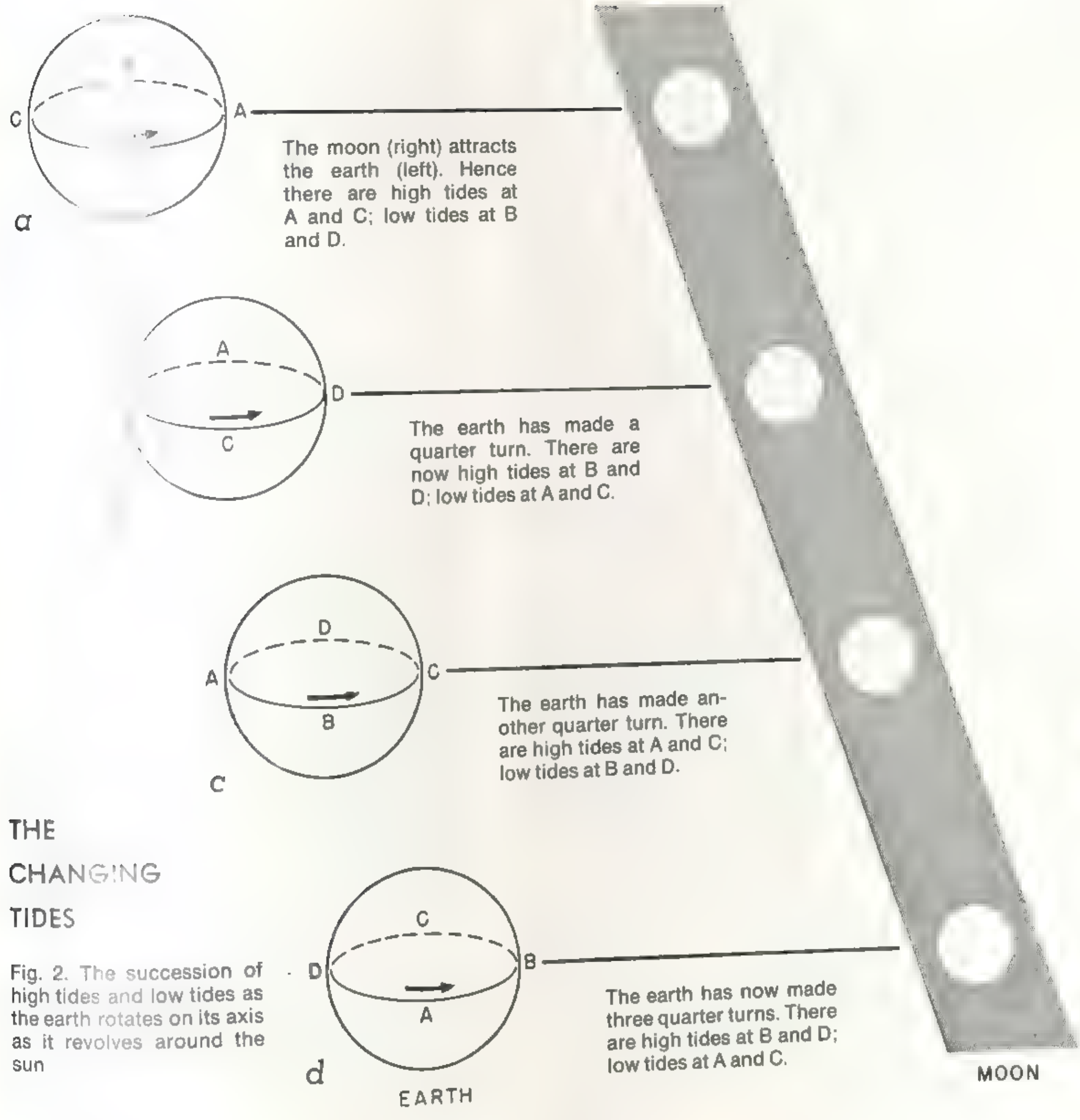
We know that the earth is constantly rotating about its axis. As a result of this rotation, a period of about 24 hours and 50 minutes elapses between successive risings of the moon. This period is called a *lunar day*. It is longer than a *solar day* of about 24 hours because as the earth is rotating, the moon is slowly revolving around the earth. The rotation of the earth, which causes the moon to appear over different parts of the earth in the course of the lunar day, causes the succession of high and low tides.

In Figure 2 we assume that the surface of our globe is covered with water. We also assume that the moon remains above the equator as the earth rotates. In *a*, A is the point nearest the moon, C the point farthest away, and B and D the in-between points. There is a high-water level at A and C and a low-water level at both B and D. In *b*, the earth has made a quarter turn. There are now high tides at D and B and low tides at A and C. The earth has made a half turn in *c*. As a result there are high tides again at A and C and low tides at B and D. In *d*, the earth has turned three quarters. Hence the tides are now high at B and D and low at A and C. With another quarter turn the cycle is complete and begins again.

We have given you some idea of how tides arise and how high and low tides succeed one another. Tidal patterns are far more complicated than our diagrams would seem to indicate, however, because they are affected by many different factors, including the effects of land masses, which were not indicated on the diagrams.

SPRING AND NEAP TIDES

We have already mentioned one of



THE CHANGING TIDES

Fig. 2. The succession of high tides and low tides as the earth rotates on its axis as it revolves around the sun

these factors—the fact that both the sun and moon are pulling at the earth. The moon's tide-raising power is greater, as we have seen, than that of the sun. Yet the sun's attraction is strong. At the time of the new moon and of the full moon, about two weeks apart, the sun, moon, and earth are approximately in a straight line. The tidal forces generated by the sun reinforce those of the moon. We then have the *spring tides*, when high tides are highest and low tides are lowest. When the moon is at first quarter or at last quarter, a straight line drawn from the earth to the moon is approximately at right angles to a straight line from the earth to the sun. The tides produced by the sun then partly cancel those produced by the moon. This results in the so-called *neap tides*, when the tidal range—the difference between depths at high and low tide—is

smallest. At Plymouth, England, for example, the tidal range is about 5 meters at spring tide, and only about 2 meters at neap tide. See Figure 3.

OTHER INFLUENCING FACTORS

The tides are affected by the distance of the moon from the earth, which changes as the moon circles the earth in its elliptic orbit. At perigee—that is, the point where the moon is nearest to the earth—the moon's tide-raising force may be 40 per cent greater than at apogee, when the moon is farthest from the earth. Similarly the tide-raising force of the sun is increased when the earth is closest to the sun.

Another decisive factor is the declination of the moon—its position north or south of the celestial equator, representing an extension of the earth's equator. As the moon journeys north or south of the equator—that is, as it increases its north or south declination—the tides show various irregularities, called *diurnal inequalities*. The declination of the sun is much less important. For one thing it takes the sun much longer to travel north or south of the celestial equator in its journey in space.

Tides are affected by the natural periods of oscillation of different parts of the ocean. To show what we mean by these periods, let us suppose that we fill a basin with water, and then set the water rocking up and down within the basin. The water will follow a definite rhythm, depending upon the length and depth of the basin. The time it takes the water to complete an up-and-down movement at one end of the basin will represent the period of oscillation.

The oceans contain a number of basins. Each basin has its own oscillation period. The force of attraction between the earth and the moon and the earth and the sun sets the water in these basins oscillating about a central point, called a *node*, where there is practically no movement. Tides will be higher in a given basin if the period of the tide is the same as the natural period of oscillation of the basin, so that the two will reinforce one another. They will be lower if the periods differ so much that they tend to cancel one another.

The Bay of Fundy, for example, lies at the very end of a huge oscillating ocean basin. Here the up-and-down movement of the water is the greatest. The natural period of oscillation of this basin is about 12 hours, which is very nearly the period of the ocean tides. The two periods reinforce one another, enormously increasing the range of the tides. This effect is even heightened because the upper part of the bay is shallow and narrow. The result is that the tidal range in the Bay of Fundy, sometimes exceeding 15 meters, is greater than anywhere else in the world.

Tides are affected by a number of other factors. Among these are the width and depth of the water subject to tidal forces. The shallower and narrower a bay, for example, the higher the tides. Changes in barometric pressure, prevailing offshore or onshore winds, and the general contour of the coastline are also important factors.

THREE TYPES OF TIDES

As a result of all these factors there are a great many different kinds of tides, varying in range from one-third of a meter or so to more than 15 meters. We can distinguish three main types. In the *semidiurnal*, or semidaily tides, commonly found in the Atlantic, the two daily high tides are about equal. The low tides are also more or less equivalent. In the Pacific and Indian Oceans, *mixed* tides are more prevalent. In these, the two high tides in one lunar day may be equal while the low tides are very unequal, or the situation may be reversed. Finally in the Gulf of Mexico, the China Sea, and other places we find *diurnal*, or daily tides. Alternate low and high tides disappear more or less completely. There is only one appreciable rise and one fall of water in a lunar day.

Because of the many factors that affect the tides, the observed times of high water do not occur when the moon is highest in the sky but show a considerable lag, which differs in different places. The interval that elapses between the time when the moon is highest in the sky and the time of the next high tide is called the *high-water interval*.

Generally speaking, tides follow the

lunar day of about 24 hours 50 minutes. Where there are semidiurnal tides, there will be an interval of about 6 hours 12½ minutes between a high tide and the next low tide, and between a low tide and the next high tide. In some places, however, the tides seem to be based on the solar day, rather than the lunar day. In Tahiti, for example, high tide takes place at about noon and midnight; low tide, at about 6 A.M. and 6 P.M. The reason seems to be that Tahiti is at the node of a basin whose waters are set in oscillation by the moon. Since there is very little relation to the tide-producing force of the moon in this nodal area, the waters follow the tidal pattern set by the pull of the sun.

The incoming tide in estuaries, inlets, and narrow bays may be transformed into a lofty and rapidly advancing wall of water, called a *tidal bore*. The best known, perhaps, is that of the Tsientang River, which flows into the China Sea. In the spring tides, the advancing wave may reach a height of 8 meters and may advance at a speed of 20 kilometers per hour or more. This towering wall of water is very dangerous to boats in its path. However, rivermen generally anticipate its coming and move their craft out of the way. Other well-known bores are those of the Amazon River, in South America, and the Severn River estuary, in England.

The tides serve as a brake on the rotation of the earth. Their friction on the ocean floor, particularly in shallow waters like the Bering Sea, robs the earth of its energy of rotation. This loss is very small. It has been calculated that it is only about 1/10,000,000,000 of the total rotational energy of the earth. However, it slows up the earth enough so that the day is lengthened by about 1/1,000 of a second every century.

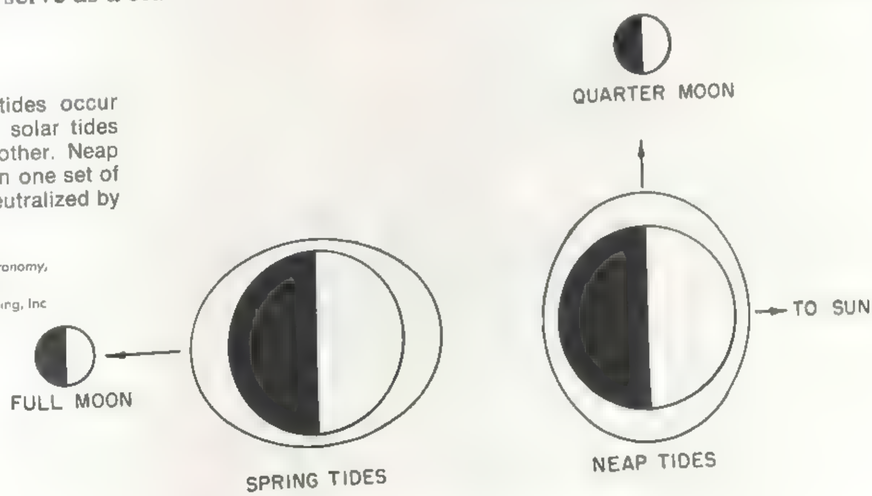
TIDAL WAVES

The name *tidal waves* is sometimes applied to destructive waves that are not produced by the tides at all, but that are caused by earthquakes, volcanic eruptions, or violent storms at sea. These waves are also known as *tsunamis*. The wave that accompanied the terrible Lisbon earthquake of November 1755 broke over the piers of the city, wrecked shipping in the Tagus River and then, racing across the Atlantic, made itself felt in the West Indies. When the volcano of Krakatoa erupted in 1883, the tidal wave that resulted caused immense property damage and great loss of life in the East Indies. A tidal wave that wreaked havoc in Galveston, Texas, in 1900 was caused by a West Indies hurricane that blew steadily for eighteen hours.

TIDAL CURRENTS

The navigators of vessels traveling along coasts are much concerned with the

Fig. 3. Spring tides occur when lunar and solar tides reinforce each other. Neap tides occur when one set of tides is partly neutralized by the other set.



Stock, Boston

Among the factors that affect the tides are width and depth of the body of water, prevailing winds, barometric pressure, and shape of the coast. Here, these factors have combined to expose a large area of the bottom during low tide

currents in the water set up by the rising and falling of the tides. When the tide is high, a harbor basin is filled to a maximum with water. At that time the currents at the harbor entrance will generally be small and variable. We then speak of a *slack current*. As the water level begins to drop, the current at the harbor entrance will be directed away from shore. The so-called *ebb current* has begun to run. The ebb current will generally reach its maximum strength some time near the halfway mark between high and low tide, when the rate of fall is the greatest. At the time of low water in the harbor basin, the currents will again become small and variable. There will again be a *slack current*.

Following low tide in the harbor basin, the water begins to flow back in the harbor. We now have a *flood current*. This current gradually increases in strength. Maximum flood is reached about halfway between high and low water. All flood currents, of course, are directed from the sea into the harbor basin. A flood current will continue to run with gradually diminishing strength until the cycle is completed with another slack current at the time of high tide.

Tidal currents follow this simple pattern in comparatively small harbors such as that of Boston, Massachusetts. Complications arise in a case like that of New York Harbor, where the whole Hudson River acts as a huge tidal basin. The sequence of currents at the harbor entrance is still slack to ebb to slack to flood, but slack currents no longer come at about the times of high and low water. A really topsy-turvy system of currents is set up in a channel connecting two tidal basins. The Cape Cod Canal

provides an excellent example. This canal connects Cape Cod Bay, with a high-water interval of 11 hours 23 minutes and a mean range of 2.8 meters, and Buzzards Bay, with a high-water interval of 8 hours and a mean range of only 1.2 meters at the entrance to the canal. Remember that the high-water interval is the period between the time when the moon is highest and high tide. The tidal currents passing through the canal are determined entirely by the difference in level at either end of the canal. The current may flow toward Buzzards Bay even when it is high tide in that bay, if the water level is higher in the Cape Cod end of the canal.

In certain straits, rapid and powerful currents called *races* are caused by the tides, particularly during the period of ebb tide. A well-known example is the Race of Alderney, between Alderney Island and the Cotentin Peninsula, on the French coast. The famous race in the narrow passage of Hell Gate, in New York City, between Long Island Sound and the East River, once made navigation difficult, particularly in the days of sailing ships. Many vessels were wrecked on reefs or rocks in the channel. Hell Gate was later made safe for navigation by blasting out some of the reefs and rocks and by dredging.

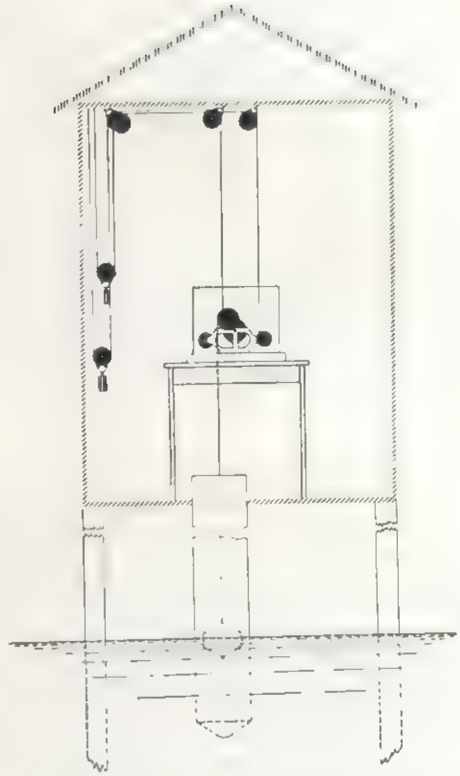
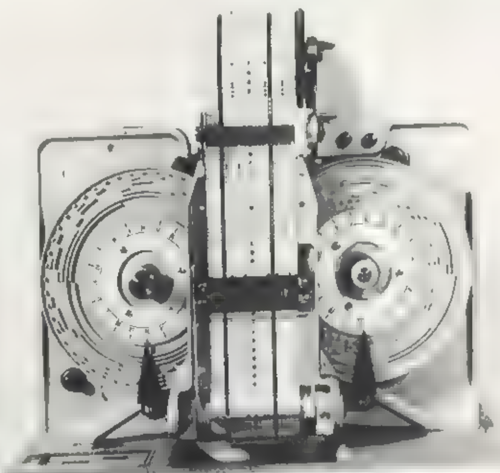


Diagram of a standard automatic tide gauge in its housing. This instrument automatically records high tide, low tide, and hourly water levels. A complete record is produced on paper.

NOAA



View of the inside of an automatic tide gauge, showing the clockworks and recording paper

When two opposing tidal currents meet, a *whirlpool* may be formed. The best-known, perhaps, is that of the Maelstrom, a strait about five kilometers wide in Norway's Lofoten Islands, between Moskenesoy and Mosken Islet. The whirlpool of Garofalo, in the Strait of Messina, is produced by winds that counteract the effects of tidal currents. The destructive effects of such whirlpools have been rather exaggerated. Small boats may be entrapped and wrecked in them, but no larger craft. However, even a large boat may find steering almost impossible until the whirlpool subsides.

MEASURING AND PREDICTING TIDES

A simple device for measuring the rise and fall of tides is a *tide staff*. This is a plank, marked in metric units, fastened in a vertical position to a pile, dock, or cliff. The top part of the tide staff must extend above the highest tide and the bottom part below the lowest tide. This device can measure the tides quite accurately where the waves are small, as in protected areas, such as bays. It is not effective, however, on an unprotected coast, where there is a constant succession of waves and swells. In such places a *tape gauge* is used. A float is suspended in a well—a large pipe set vertically in the water with openings below the lowest possible level at low tide. A tape with appropriate markings is attached to the float. This tape passes over a pulley and a counterweight is set at the other end of the pulley. By reading the markings on the tape, observers can measure the tide.

The same principle is used to record automatically the rising and falling of tides in the standard automatic tide gauge used by the United States in its National Ocean Survey. In this case the float in the well is attached to a wire that passes over a pulley and causes it to turn as the water level rises or falls. The pulley is mounted on a rod with threads like those of a screw. As the pulley turns this way or that, a carriage with a pencil moves in one direction or another along the threads of the rod. The pencil on the carriage makes a continuous line on paper wrapped around a roller that is turned by clockwork. The roller turns at the rate of about two centimeters an hour. A complete record of the tide can be obtained by examining the markings on the paper. High water and low water are recorded, as are the hourly levels.

For accurate tidal predictions the mariner uses the excellent *Tide Tables*, published every year by the U.S. National Ocean Survey. One volume is published for the Pacific and Indian oceans and another for the Atlantic. They may be purchased for a low price at the U.S. Government Printing Office in Washington and are indispensable handbooks for all who are interested in the tides.

In the *Tide Tables*, an extensive basic table gives the times of high and low water on each day of the year for a limited number of reference stations along the coast. An auxiliary table makes possible the calculation of the times and heights of high and low water for numerous subordinate stations all along the coast. Still another table gives the information needed to calculate the height of the tide at any time between high and low water.

Mechanical devices are also used to predict the tides at a given place and time. The tide-predicting machine employed by the National Ocean Survey is a rather complicated device that automatically

Tide staff—a simple device for measuring the height of the tide.

NOAA

takes into account more than twenty factors affecting the tides. It can predict the time and height of the tide at any place in the world, provided that the local conditions, such as the depth of water, shape of the coast, and so on, are known.

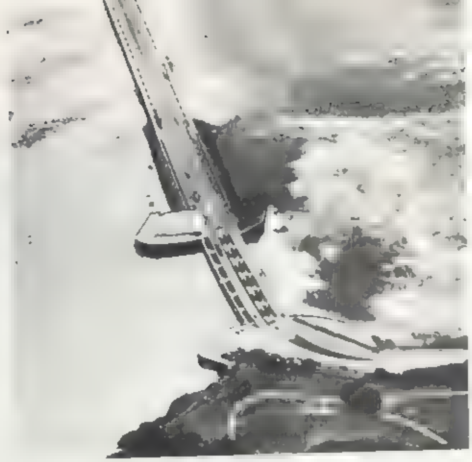
It is possible to predict the height of the tide at any particular time without elaborate tables or machines. Suppose you know from your almanac or local paper that low tide occurs at 9 A.M., that the next high tide is at 3:15 P.M. (1515 in the *Tide Tables*), and that the height of high water is 2.7 meters above the low-water level. You would like to know how much water can be expected at 11 A.M. in a channel in which the normal low-water level is 3 meters.

You use a simple rule of thumb—the 1-2-3-3-2-1 rule. Note that the sum of these figures is 12. The rule states that, following low tide, the water rises by $\frac{1}{12}$ of the range in the first hour, by $\frac{2}{12}$ of the range in the second hour, by $\frac{3}{12}$ in the third hour, by $\frac{3}{12}$ in the fourth hour, by $\frac{2}{12}$ in the fifth hour, and by $\frac{1}{12}$ in the sixth hour. Between 9 A.M. and 10 A.M. the water should rise by 0.23 meters; between 10 A.M. and 11 A.M. by $2 \times 0.23 = 0.46$ meters. At 11 A.M., therefore, the height of the water in the channel should be equal approximately to 3 meters (the height of the channel at low tide) plus 0.23 meters plus 0.46 meters = 3.39 meters.

POWER FROM THE TIDES

Obviously the periodic movement of vast masses of water, such as we find in tides, represents vast stores of potential power. In Europe, hydroelectric companies have used this power to generate electricity. A dam, in which turbines have been placed, is built between a tidal basin and the sea, or between two basins. The water flowing from the sea to the tidal basin, or from the tidal basin to the sea or from one basin to another is made to operate turbines. These are connected to dynamos, which generate electricity.

The United States has experimented with tidal energy since the seventeenth century. The first use of tidal energy in the country was to provide power to turn mill wheels to grind corn and spice.



French Embassy Press and Information Service

This plant on the Rance River in Brittany, France, converts tidal energy into electricity.

More sophisticated power plants have been proposed since then. In 1935, construction started on a 250,000 kilowatt power plant in Passamaquoddy Bay, Maine, an inlet on the Bay of Fundy, on the Canadian border. The project ended soon after because the U.S. Congress failed to provide funds for its continuation. In 1948, however, an international study involving the United States and Canada was set up to reevaluate the project. The study concluded that the electric generating capacity of the facility could be expanded, but that it was "economically unfeasible."

In 1961, the project was again restudied—this time by the U.S. government alone. The U.S. Department of the Interior proposed that the generating capacity of the plant be increased to 1,000,000 kilowatts. The power generated by the plant would be used only during periods of peak demand for electricity. There has been no action on this proposal.

Outside the United States, progress has been made in harnessing tidal energy. France has constructed a working power plant based on the power of the tides in the Rance estuary in Brittany. The generating capacity of the plant is 240,000 kilowatts. The overall efficiency of the operation is about 25 per cent.

The Soviet Union has also built a small plant in the Kislaya Inlet. The plant is based on the French model, but it is on a much smaller scale. The output from the Soviet facility is only 400 kilowatts.

OCEAN CURRENTS

The huge and restless ocean has a complex circulation system, made up of a variety of currents. Each of these represents a definite mass horizontal movement of water. The moving mass may be a shallow, narrow rivulet, flowing along the surface of the sea, or it may be a deep, wide flood, transporting millions of metric tons of water along its path. The direction of flow—called the *set* —may be constant. It may vary constantly. It may change abruptly from one direction to the opposite one.

The velocity of the moving water mass may be barely measurable, or it may come to as much as four knots. A knot is a unit of speed equivalent to 1,850 meters per hour. The speed of a current generally decreases with depth. Very often both the speed and the direction change, so that beneath the surface there may be a current flowing in an opposite direction to the surface flow.

It has taken many years of study and observation to discover, classify, and understand these water movements. The first currents to be studied, naturally, were those that could be observed from the shore. By watching the drift of a log or some other bit of flotsam, an observer could easily measure the direction and speed of a surface current. He could repeat the operation as often as necessary in order to note the changes in speed and direction that might occur from day to day.

This method of observing offshore currents is still employed. It is effective because as long as an observer remains on shore, he has a fixed position from which to measure the relative speed and direction of the current, and he can make frequent observations. Matters become more complicated when currents are mapped in the vast open stretches of the sea. When the observer is in a moving boat, the only fixed position in the vicinity is the ocean bottom, and this may be several kilometers beneath the ship.

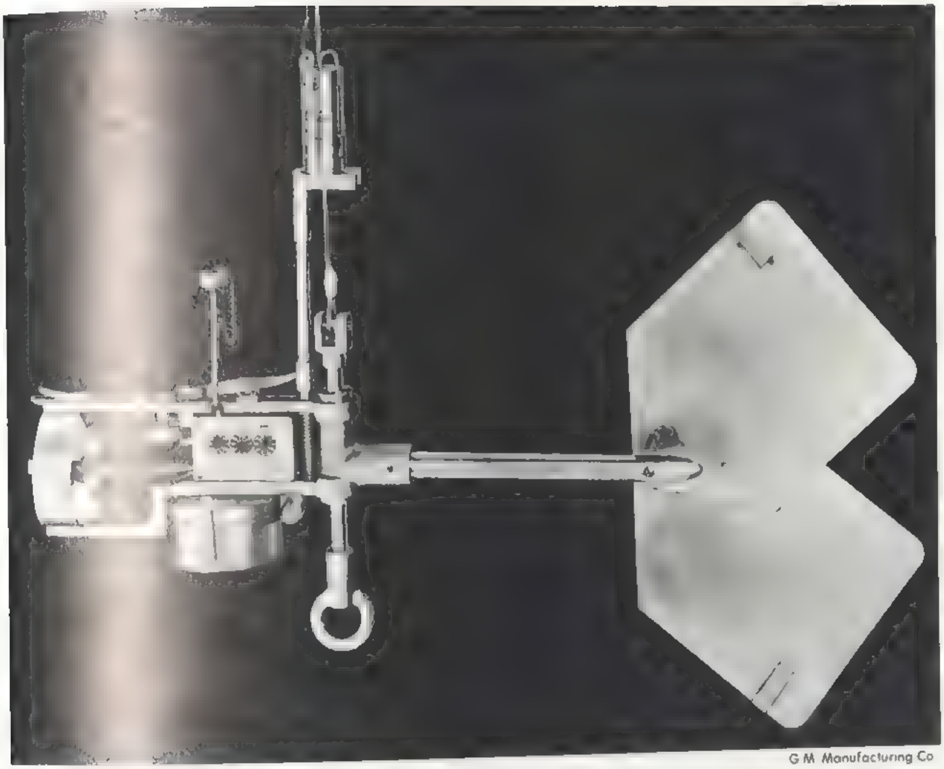
To maintain some sort of fixed position at sea, a ship engaged in mapping currents must cast anchor and remain at the same spot for a certain length of time. Specially equipped oceanographic vessels have anchored in over 4,500 meters of water for periods as long as two weeks. Of course, even when a ship is at anchor, its position is not absolutely fixed, since it will move about with the changing currents and winds.

DIRECT MEASUREMENT OF CURRENT

The currents are measured in various ways. The speed may be determined by a current meter. This consists of an open tube that is kept headed toward the direction of flow by a vane. Inside the tube is a propeller, which is turned by the water flowing through the tube. The number of turns per second or per minute are recorded and from this the velocity of the current is calculated. To determine the direction of flow, buoys are set adrift. Their direction and distance are checked at intervals from the ship. Sometimes vessels follow a buoy to note its direction over considerable periods of time.

The ingenious device called the Ekman current meter measures both the speed and direction of current flow. Speed is indicated by a propeller set in a tube, as described above. Direction of flow is measured by means of a compass box rigidly attached to the vane of the meter. The box is divided into 36 compartments arranged in a circle. Each compartment corresponds to an angle of 10 degrees and is marked "N," or "N 10° E," or "N 20° E," and so on, according to its position. A system of magnets swings freely over these compartments. The magnets are attached to a frame that turns with them. A grooved bar is connected to the frame. At intervals a small ball drops through the bar into one or another of the compartments under it. The average direction of the current is calculated by seeing how the balls are distributed in the various compartments of the box.

The Woods Hole Oceanographic Insti-



G M Manufacturing Co

A current [illegible] similar to the Ekman meter. This instrument measures both the speed a[illegible]ction of current flow. Such devices were a great improvement over the [illegible]es-old drift-bottle method of determining ocean currents.

tution in Massachusetts has developed a method of mapping currents from a moving ship by means of towed electrodes. The earth's magnetic field serves as a frame of reference in this method. A rapid temperature-measuring device, called a bathythermograph, can also be used from a moving ship.

The method most commonly used to map currents in the open ocean is to reckon how far a ship is driven, in a given length of time, off the course that has been charted for it. Current charts are based chiefly on this method. It does not require specially equipped vessels. Therefore regular merchant ships can send in routine forms containing information on the subject to the appropriate hydrographic office.

For the best results it is necessary that the position at the beginning and the end of the run should be known precisely and that the run should be of short duration. If celestial navigation is employed exclusively, these ideal conditions are comparatively rare, since the ship's position is seldom calculated more than three times a day. However, since the introduction of *loran*, it is possible to get accurate positions very frequently. In this method the navigator uses radio signals from several shore positions to enable him to check the position of the ship.

The drift-bottle method, devised over a century ago, is sometimes used to study the larger circulation patterns. A card containing the name and address of an oceanographer or hydrographic office is put into a bottle. This is ballasted so that it floats just submerged beneath the surface and is then sealed. A number of bottles prepared in this way are cast adrift. They may be picked up by fishermen pulling in their nets. If any

bottles are cast up on land they may attract the attention of passers-by. The person finding a bottle is asked to write on the card when and where he picked up the bottle and then to mail the card.

The drift-bottle method has been used most often in coastal areas, although many of the bottles have crossed the oceans. This method leaves much to be desired. For one thing, it is rarely known how long a bottle may have rested on a beach before being picked up. Besides, it is quite a difficult problem to calculate the course the bottle may have followed during the period it was adrift.

INDIRECT MEASUREMENT

In some cases ocean currents are not measured directly. Instead, the oceanographer studies the density patterns of the various water layers, as determined by temperature and salt content, at each of a network of stations. The saltier or colder a water layer is, the denser it is. Dense layers lie below lighter ones. Once the density patterns have been established at each of the stations, the oceanographer can identify different masses of water and can trace their movements.

Another method of tracking currents is the neutral-buoyancy float. This device is set to sink to any desired depth. As it moves along, it emits sound signals that are picked up by hydrophones aboard ships. The float thus provides information on the directions and velocities of the oceanic currents.

The water itself can be made to reveal its movements. Special dyes trace the directions of currents for kilometers. Radioactive substances also added to the water (sometimes to the sediments transported by moving water) are tracked by means of radiation-detecting instruments on ships. One such method uses floating devices that inject radioactive matter into the water and others that detect the radiation and so discover the patterns of currents.

THREE MAIN TYPES OF CURRENTS

As a result of investigations by all the methods that we have described, it has been found that there are three principal types of ocean currents. They are (1) the tidal currents, or currents associated with the attraction of the sun and moon; (2) the wind-driven currents, or wind drifts, caused by friction between the wind and the surface of the sea; (3) the currents related to the distribution of density in the sea.

TIDAL CURRENTS

Long before people ventured out on the broad seas, they must have become quite familiar with the periodic rise and fall of the tides along the shore. Early Chinese writings mentioned the tides, but their explanations of the phenomenon were quite fantastic. The 16th-century astronomer Johannes Kepler first associated tidal ebb and flow with the various phases of the sun and moon. The 17th-century British physicist Sir Isaac Newton formulated the theory upon which the modern understanding of the tides is based. This theory was later somewhat modified by the 18th-century French astronomer-mathematician Pierre Laplace and others.

Tides are enormous waves produced by the gravitational effects of the sun and moon on the surface of the earth. These waves form a complex pattern covering all parts of the ocean. When they reach the shore, the water level rises and it is *flood tide*. It is *ebb tide* when the waves recede and the water level falls. The range of tides—that is, the difference in height between high and low water—is greatest where the water is confined, as in a bay, and least on the shores of small islands far out at sea.

The moving water in tides constitutes the tidal currents. Their direction and speed depend not only on the state of the tide but also on the depth of the water and the proximity of the shore line. The swiftest currents are found in the narrow entrances to bays or sounds. In some rivers that empty directly into the sea, the rising tide will cause a current to flow many kilometers up the river. In certain cases the incoming water races over shoal stretches at such a rate as to form a wall of water known as a *bore*. The velocity of tidal currents in

Woods Hole Oceanographic Institution

Ocean currents can also be measured from a moving ship by towing electrodes behind the ship. The onboard instrument shown at right, a geomagnetic electrokinetograph, gives a direct reading of the speed and direction of the current.

the open sea is small and is often masked by other water movements.

WIND CURRENTS

Like tidal currents, wind currents occur in all parts of the sea. Wherever and whenever the wind blows across the surface, it exerts a stress upon the water. If the stress is great enough and is continued long enough, the water begins to move, slowly at first. The surface film is the first to be affected. Gradually the water beneath it is also set in motion. The depth of the current will depend upon the strength of the wind and on the length of time it continues to blow in one direction.

The situation is complicated by two factors: (1) the water is generally not homogeneous from top to bottom; (2) the earth is not motionless. If, for instance, a layer of light, warm water overlies colder, heavier water, the mixing due to turbulence will be checked and the current will be shallower than if this difference in density did not exist. Likewise, the direction of flow is altered from the surface downward, because of the earth's rotation about its axis. This deflection is known as the *Coriolis effect*. The deflection is to the right of the direction in which the wind blows in the Northern Hemisphere, to the left in the Southern. It averages about 45° at the surface and increases with depth until the current actually flows in a direction opposite to the surface flow, although at a slower rate.

The first person to note the difference between the direction of surface water flow and the direction of the wind was the Norwegian explorer Fridtjof Nansen. While his ship, the *Fram*, was drifting in the polar seas in 1893–96, Nansen discovered that the ice drift was from 20° to 40° to the right of the wind direction. The direction in which a wind-driven current flows is also influenced by the depth of the water. In

shoal water it flows more directly before the wind. Direction is also affected by the contour of the coast and by the proximity of other currents.

The wind blows most consistently in one direction in the southern seas around Antarctica, in the northeast and southeast trade-wind belts, and in the belt of the westerlies in the northern oceans. In all these areas we find extensive wind currents many kilometers in width but rarely as much as 100 to 125 meters deep. Since the wind velocity fluctuates with the seasons in these areas, the current speeds also change from month to month. The direction of flow, however, is comparatively steady. Because of these wind systems, there is in each of the great ocean basins a general movement of the surface water toward the west near the equator and toward the east about halfway between the equator and the poles.

Near certain large land areas, particularly southern and eastern Asia, there are winds, called *monsoons*, that are just as constant as the trade winds and the westerlies but that blow in directly opposite directions winter and summer. In winter, because of the generally higher pressure over the land, the wind is offshore. In summer, because of the warmer air and correspondingly lower pressure over the same land area, the wind is onshore. The currents set up in the ocean by these winds are known as monsoon drifts. The best known are in the northern Indian Ocean.

Other wind drifts with more or less regular periods are caused by local changes in wind direction along the coasts. In the daytime the land becomes more heated than the waters offshore. The warm air rises and is replaced by the colder air flowing in from the sea. At night the land cools quickly, but the ocean retains most of its heat. It is now warmer than the land. The comparatively warm air over the sea rises and is replaced by colder air from the land. Hence surface winds blow from the sea to the land by day and from the land to the sea at night. These changing breezes affect the offshore currents.

All these regular currents near the coasts, combined with the effects of periodic changes in temperature of the water masses, naturally have marked effects upon the tides. In fact, they themselves may be considered as tides because of their periodic nature. They are called meteorological tides, as opposed to the astronomical tides due to lunar and solar attraction.

The interaction of wind and water can produce some interesting effects. In coastal regions, wind blowing parallel to the shore can cause upper layers of near-shore water to be blown offshore. This deficit is then filled by bottom layers moving upward. These *upwelling* layers carry a great deal of dissolved nutrients with them and tend to be very active biologically. An example of such an upwelling area is the region off the coast of Peru. These rich waters usually support a large anchovy fishery. If, on the other hand, surface waters tend to pile up near shore, a region of *downwelling* is established.

CURRENTS RELATED TO THE DENSITY DISTRIBUTION

We use the term "related to the density distribution" in describing the currents of the third class because a number of factors, direct and indirect, contribute to their formation. These currents include the Gulf Stream in the North Atlantic, the Kuroshio, or Japan Current, in the Pacific, and other important water masses. Wherever they occur, there is a characteristic pattern of density within the ocean. If all the other forces acting on the current were to cease functioning, the current would continue to flow, at least for a time, because of the density distribution.

To understand how density distribution can cause water to move, let us suppose we have a tank divided by a partition into two sections, one of them containing cold water and the other warm water. If we remove the partition separating the two masses of water, the colder, heavier water will sink and spread out toward the bottom of the tank, while the warmer, lighter water will flow out over the surface until there will be a new distribution of densities—a layer of light water over a layer of heavier water. After the water in the tank reaches a

state of equilibrium, with lighter water over denser water, suppose a current is set up at the surface by a wind produced, say, by an electric fan. The lighter surface water will be moved, at least in part, to one end of the tank, thus again changing the density distribution.

Density patterns connected with the transport of masses of water are due to wind currents, tidal currents, and heating and cooling processes, as well as to evaporation and precipitation, which alter the salt content of the surface water and therefore change its density. The most important of these factors are the wind currents. Tidal currents are generally too small and short-lived to cause any large-scale density changes. Heating, cooling, precipitation, and evaporation are such slow processes, comparatively speaking, that without the help of the winds these processes could hardly bring into being any large-scale movement of water.

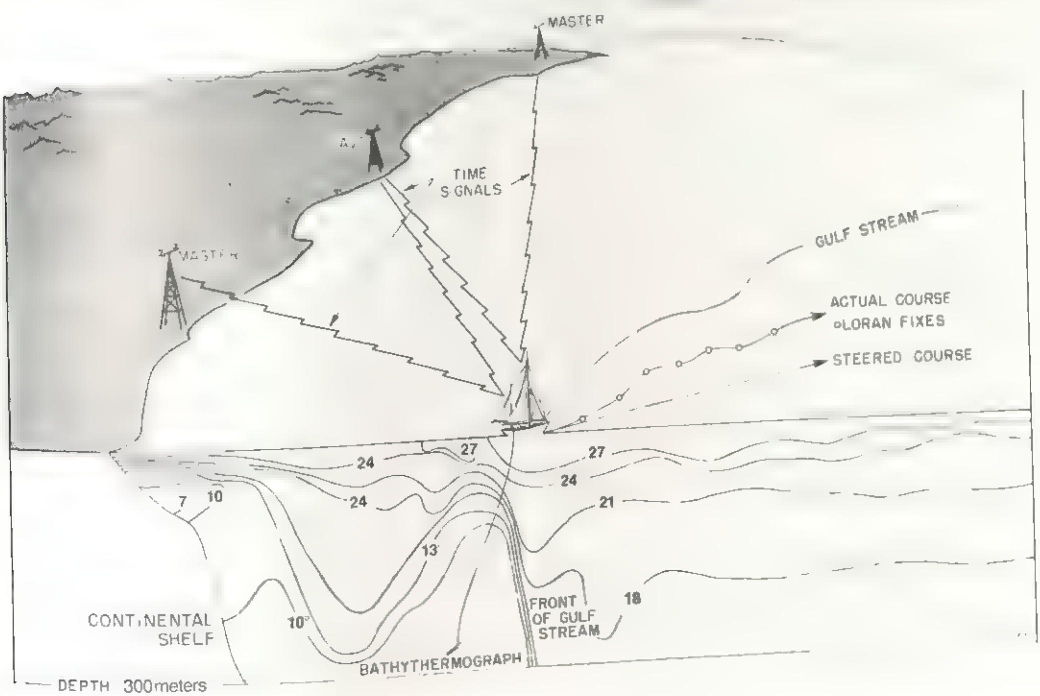
MAJOR CURRENTS

Certain major currents have been named after the land areas past which they flow or after various oceans. The names of others indicate their position with respect to the equator or the prevailing wind in a given area. Thus we speak of the Peru Current, the Brazil Current, the North Atlantic Current, the South Equatorial Current, and the West Wind Drift. This system is simple and in some cases it works quite well. However, there are certain objections to it. For one thing, although an ocean current may follow a well-defined path with only minor fluctuations, it is seldom possible to define its point of origin or its end. In a sense, currents are endless, even though they constantly change in character.

It has been pointed out that it seems quite illogical to name an entire system of currents after one of the currents of which the system is composed. For example, the

In one survey of the Gulf Stream, a ship zigzagged in and out of the main current, making subsurface temperature recordings. The drift of the ship was checked by means of radio signals from several shore locations.

Woods Hole Oceanographic Institution



Ocean currents exert considerable influence on the climate of the shore areas near where they flow. Here a barren, dry area near Talara, Peru. Winds that pass over the cold Peru Current, flowing along the western coast of South America, are warmed as they reach land and do not give up their moisture. The result: barren land with a dry climate.

Exxon Corp

name "Gulf Stream" has been applied to the system of currents extending from the Florida Straits to the northern tip of Norway. It received its name because of its supposed point of origin, the Gulf of Mexico. We now know that the so-called Gulf Stream does not originate in the Gulf of Mexico, but is a continuation of a flow through the Caribbean, which in turn is fed by westward-flowing equatorial currents and so on. The force of traditional practice is strong, however. Therefore, oceanographers still refer to this system of currents as the Gulf Stream, or Gulf Stream system. Curiously enough, they also use the name Gulf Stream for one part of the system, extending from Cape Hatteras to south of the Grand Banks.

Let us now briefly chart the major ocean currents of the world, which are shown in the map on page 259.

Southern hemisphere currents. Encircling the Antarctic continent and spreading as far north as 40° south latitude is the broad West Wind Drift, flowing in an easterly direction. The West Wind Drift is also known as the Antarctic Drift, or the Antarctic Current.

As it approaches each of the great land masses to the north—South America, Africa, and Australia—its northern portion is deflected in a northerly direction, thus carrying a huge mass of cold water up along the western coast of each land area. In the Pacific this northerly flowing branch, off the western coast of South America, is called the Peru Current. It was formerly known as the Humboldt Current. In the Atlantic, the branch flowing along the western coast of Africa is the Benguela Current, named after the Benguela district of Angola. The Indian Ocean branch, flowing off the western coast of Australia, is called the West Australian Current.

All these moving water masses branching off from the West Wind Drift are strongly influenced by the southeast winds that in general prevail off the western coasts in the Southern Hemisphere. The currents are narrower and in general swifter than the

West Wind Drift from which they are derived.

Just south of the equator—0° to 10° south latitude in the Atlantic and Pacific and somewhat farther south in the Indian Ocean—the southeast winds are known as the southeast trades. Here the currents spread out and move toward the west. They merge with a broad westward flow, the South Equatorial Current. In the Pacific the South Equatorial Current is farther to the north than in the Atlantic.

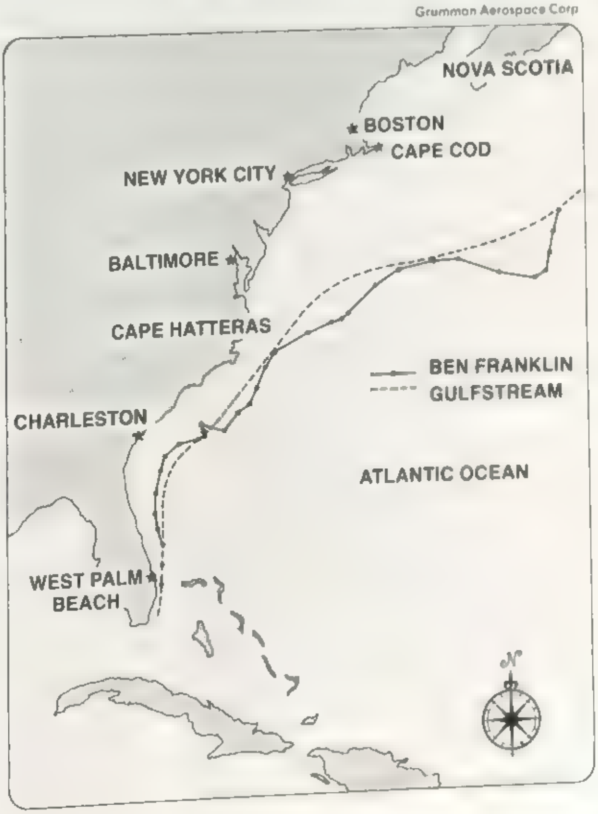
On approaching the western boundaries of the Atlantic and Indian oceans, this current divides. One part crosses the equator and moves north; the other moves south. In the Pacific, the South Equatorial Current does not branch off in this way, but turns south. In each southern ocean, therefore, there is a movement of cold water in a northerly direction on one side of the ocean and a southerly movement of warm water on the other side.

The southward-moving current in the South Atlantic is called the Brazil Current: that in the Indian Ocean, the Agulhas Current. In the South Pacific the southern flow extends over the whole western half of the ocean. At 40° south latitude, approximately, these southward-flowing currents turn to the east and become part of the West Wind Drift. Thus each of the major current systems in the South Atlantic, the South Pacific, and the southern part of the Indian Ocean completes a counterclockwise circuit. It makes up a huge whirlpool, known as a *gyre*.

There is another important current in the South Atlantic—the Falkland Current. Part of the West Wind Drift is deflected through the Drake Passage, between Cape Horn and the South Shetland Islands, and flows between and around the Falkland Islands. It then moves up the east coast of South America as a cold current nearly to the mouth of the Rio de la Plata.

Northern hemisphere currents. In the northern oceans the circulation patterns

Grumman Aerospace Corp



Map showing the path of the submersible ship Ben Franklin that drifted with the Gulf Stream and the actual path of the current. Scientists found the Gulf Stream to consist of several colliding currents and to vary in speed along its path.

are quite different. The oceans are more or less hemmed in by land in the vicinity of the polar sea. The boundaries are more irregular. The over-all circulation is clockwise, instead of counterclockwise. In general, the currents of the northern oceans are somewhat swifter and deeper than those of the south. In high latitudes the current pattern is much more complicated.

In the equatorial regions of the North Atlantic and North Pacific, between about 10° and 20° north latitude, the wide and slow-moving North Equatorial Current flows toward the west. In the northern part of the Indian Ocean, because of the great land mass of Asia that closes it in, the winds are of the monsoon variety. The current flow known as the Monsoon Drift is westerly during the winter and easterly in the summer.

In the southwestern part of the North Atlantic, part of the North Equatorial Current flows north of the West Indies and becomes the Antilles Current. The rest enters the Caribbean Sea, where it is joined by part of the South Equatorial Current. The combined flow pours out of the Caribbean into the Atlantic and is joined by the Antilles Current off northern Florida. The part of the Gulf Stream System from Florida Strait to Cape Hatteras is called the Florida Current. The part from Cape Hatteras to south of the Grand Banks, as we have seen, is known as the Gulf Stream.

In the Pacific, the waters of the North Equatorial Current divide off the Philippines. One part turns north and forms the Kuroshio, or Japan Current. The other part veers toward the south; after a time it turns eastward and forms an Equatorial Countercurrent between the westward-flowing North and South Equatorial currents.

At approximately 40° north latitude, the Gulf Stream and Kuroshio start eastward, forming respectively the North Atlantic and North Pacific currents. On reaching the eastern end of the ocean, part of each current turns south, becoming the Canaries Current in the Atlantic and the California Current in the Pacific. Later these merge with the westerly flowing North Equatorial Current, completing a clockwise circuit. Thus we have two major gyres, or whirlpools, in the oceans of the Northern Hemisphere: one occurring in the North Atlantic Ocean, the other occurring in the North Pacific Ocean.

The big gyre in the North Atlantic encloses what is called the Sargasso Sea, an area of comparatively still water where vast masses of floating sargassum, or gulfweed, accumulate. In some places they form immense mats of vegetation that look like islands.

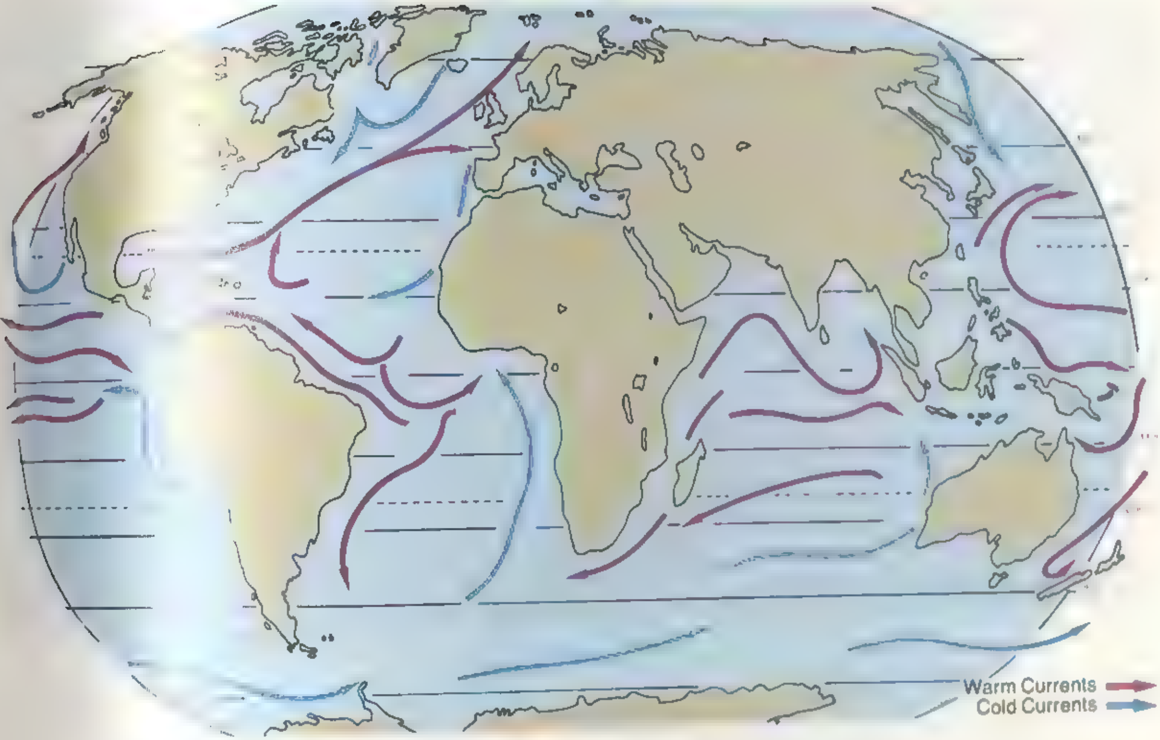
A large part of the North Atlantic Current does not turn to the south but flows up along the coast of Europe. Some of it curves back to the west, and forms the Irminger Current, south of Iceland. The rest enters the Arctic Ocean as the Norwegian Current. In the Pacific a part of the North Pacific Current turns north and becomes the Alaska Current.

The cold currents known as the Labrador Current, in the Atlantic, and the Oyashio, in the Pacific, flow south from the Arctic regions to about 45° north latitude; there they divide. One part of each curves eastward to join the North Atlantic Current or North Pacific Current. The other moves in a southwesterly direction and forms a wedge between the coast and the warm waters from the south.

In the northern part of the Atlantic the East Greenland Current flows south along the eastern coast of Greenland. Joined by the Irminger Current southwest of Iceland, it curves around the southern tip of Greenland. Then it flows north through Davis Strait into Baffin Bay. Here it makes another turn and becomes the Labrador Current.

COUNTERCURRENTS.

Oceanographers have found that under each major oceanic current there is, at varying depths beneath it, a powerful countercurrent moving in the opposite direction. For example, under the Gulf Stream, a countercurrent flows from north to south in the western Atlantic Ocean. Along the eastern coast of South America, a deep countercurrent moves northward. These countercurrents are apparently part of a worldwide system.



EFFECTS OF CURRENTS

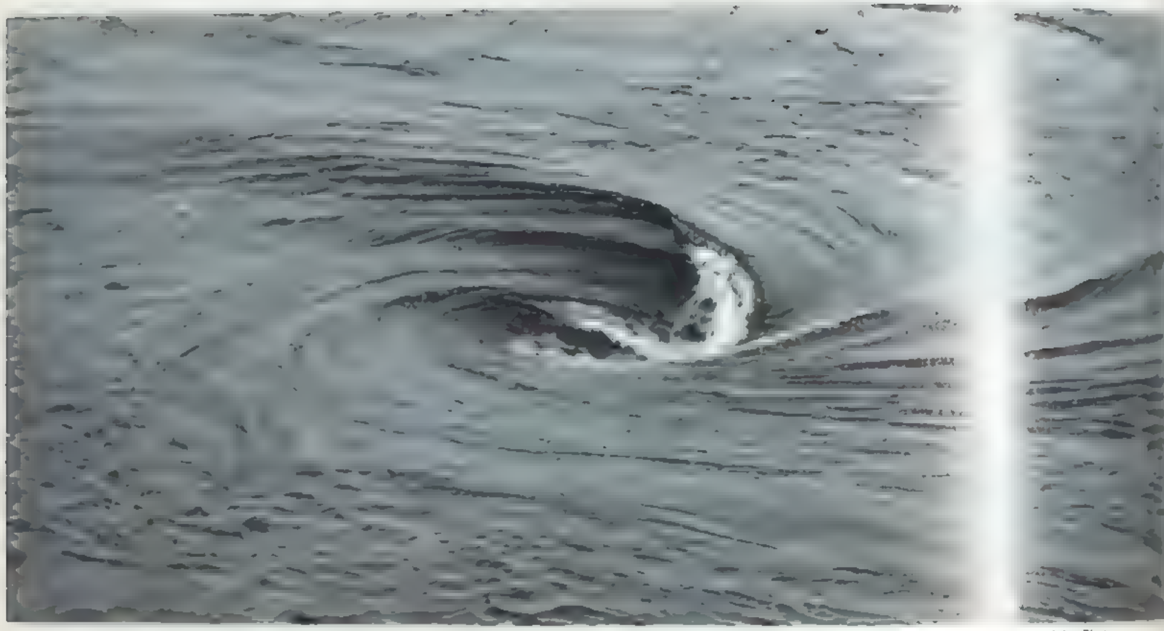
The great currents we have just described obviously affect navigation. A current with a velocity of two knots adds two knots to the speed of ships sailing with it and reduces the speed of ships moving against it by the same amount.

The major ocean currents have an important effect on climate as they transport huge masses of warm water to higher latitudes and of cold water to lower latitudes. They act particularly through the agency of the winds that sweep over them. For example, the warm waters of the North Atlantic Current (forming part of the Gulf Stream system, as we have seen) temper the climate of northern Europe as moisture-laden winds from the sea pass over that area. On the other hand, the Gulf Stream has comparatively little effect on the climate of the eastern United States, since the winds that pass over that section often blow from the northwest toward the ocean. On the other hand, the cold Labrador Current brings "nine months winter and three months bad weather" to Labrador and eastern Newfoundland.

CONTINUING STUDIES

The effects of currents is a continuing area of study. In the late 1960s a specially constructed submersible ship, named the *Ben Franklin*, was used to learn more about the Gulf Stream and its possible effects on navigation, climate, and the biological activity of the water.

The ship with a crew of six joined the Gulf Stream current off the southern coast of Florida and drifted with it for 30 days, covering a distance of some 2,600 kilometers. The project, headed by the Swiss oceanographer Jacques Piccard, recorded not only the direction and speed of current flow, but also photographed the ocean floor; took temperature, salinity, gravity, and magnetic readings; and studied the plant and animal life of the current area. They found, among other things, that the Gulf Stream is made up of colliding currents.



Atlas Photo

THE DEPTHS OF THE SEA

by Francis P. Shepard

A hundred years ago, the question "How deep is the ocean?" would have remained unanswered. Measurements had been made, it is true, in the shallow water along the coast, but exploration of the deeper portions of the ocean had scarcely begun. For one thing, the sounding method used in those days was decidedly primitive. A weight was lowered to the bottom of the sea on a hemp rope. After it had reached the bottom, it was pulled up again. It took the better part of a day to make a sounding in depths of three to five kilometers, such as in most of the sea. In the course of the years that followed, the sounding technique improved somewhat, but it was still based on the principle that we outlined above, and sounding continued to be slow and tedious.

By the 1920s, a new and revolutionary technique, called *echo sounding*, had been introduced. This method made it possible to obtain the depth of the ocean at any given locality in a matter of seconds instead of hours, as formerly. This is how echo sounding works. A plate on the bottom of a ship is tapped, and sound waves move away from it in a cone. Upon reaching the bottom, they bounce back as echoes and are received in an instrument called a hydrophone, which is installed in the bottom of the vessel. The time the sound takes to hit the bottom of the ocean and return is measured by an ingenious mechanism. Since the speed of sound is known, the ocean depth can be calculated very easily. A continuous record of the water depth under the vessel's keel is made on a roll of paper run through the sounding apparatus.

By using echo soundings, scientists have been able to gain an increasingly detailed picture of the floor of the ocean all around the world. The major maritime nations have sent ships on long surveying expeditions. Men have descended to the greatest depths of the sea in a special research vessels. Cameras have been used to

photographs of the deep ocean floor. And there are scientific programs for drilling into the sea floor and taking samples for study. The result of all this has been a radical change in our ideas about the bottom of the sea.

When I was a student in college, I was taught that the floor of the deep ocean was a flat plain. The shallow-water areas were also considered to be extremely flat. The floors of lagoons lying inside coral reefs were compared to billiard tables. We know now that all this was quite wrong. There are some flat areas on the ocean bottom, it is true, but for the most part the surface is certainly at least as uneven as that of the land. Echo soundings have revealed many interesting features. Submarine canyons comparable to the largest canyons found on land are known to exist in the ocean. There are also lofty mountains and great deeps. Some of the peaks are tall enough to form islands.

The ocean bed may be divided into three major provinces, or areas, on the basis of depth. First, there are the *continental shelves*, which are relatively flat areas that border the continents. Water depths are usually less than 120 meters. At the edge of each continental shelf there is a zone where the slope increases greatly. The areas where such zones are to be found are called *continental slopes*. They extend to depths of a kilometer or even more. Finally, beyond the slopes are the deep portions of the ocean, which make up about two thirds of its total area. In the pages that follow, we shall consider each one of the three provinces in turn.

THE CONTINENTAL SHELVES

The continental shelves, which make up about seven per cent of the ocean area, have been widely explored. Hundreds of millions of soundings have been taken of the depths on the shelves. Hundreds of thousands of bottom samples have been obtained. The ocean bed in these areas has been photographed in many places. It has been explored by divers and by swimmers using aqualungs.

The shelves average 65 to 70 kilometers in width. The average water depth is 60 meters. The average depth at the outer edge of the shelves where the slide to the deeps begins is 120 meters. The outward slope from the land is about two meters per kilometer. Minor irregularities are found in the shelves.

If a great tidal wave should suck away the water and expose a typical continental shelf to our view, it would look like a mass of sand dunes dotted with myriads of small depressions. In the shallow portions, there would also be a great many rocks, more or less covered with growing plants and animals. Some of these "rock gardens" would be extremely colorful and would afford a field day to the color-camera enthusiast. There would also be numerous terraces, with gentle slopes between the different terrace levels.

The continental shelves in regions where glaciation, or glacier activity, has taken place are much deeper than in other areas. In many of these glaciated regions, depths of 300 meters or so are found near the coast, while the outer parts are relatively shallow. The deep areas of such shelves may extend up wide bays, such as the Bay of Fundy and the Gulf of St. Lawrence in eastern North America or narrow bays, such as the steep-sided fiords of Norway and Alaska.

On the outer portions of shelves subjected to glaciation are found the shallows known as *banks*. The Grand Bank, off Newfoundland, and Georges Bank, off

This satellite photograph hints that our planet should be called "Ocean" rather than "Earth."

Space Science and Engineering Center, University of Wisconsin

Life is abundant in the upper levels of the sea, but can also be found at great depths. These fishes live 5,000 meters below the surface.

New England, are good examples of this type of ocean-floor structure. The banks were built up of material that the glaciers had stripped from the land surface. The waters in the bank areas are often very shallow. Fish are found here in vast numbers. The glaciers were kind to man. They gouged out numberless deep harbors for him along the coasts and erected banks for his fish supply farther away from land.

The continental shelves off many tropical landmasses are marked by coral reefs that rise from the shelf floor almost to the surface of the sea. Actually, coral makes up a rather small per cent of the total structure of the reefs. In their development, however, the little animals called corals play a very important part. The reefs grow upward like a tree, developing numerous branches and stalks. In this framework, other organisms besides co[illegible] live and contribute to the production [illegible] solid but porous mass of limestone [illegible] Observations have shown that corals [illegible] capable of growing up toward the surface [illegible] rate of 30 centimeters in ten years. [illegible] it is very doubtful if an entire reef ever grows at such a rapid rate. Generally speaking, coral reefs are formed only in water less than 90 meters and no cooler than about [illegible] Celsius.

The so-called *fringing reefs* are formed along coastal areas. Sometimes reefs develop off the shores of islands or continents, forming a barrier separated from the land area by *lagoons*. These are called *barrier reefs*. Other coral reefs are found far away from land. We shall discuss them later in this article. The largest group of reefs in the world is to be found along the northeast coast of Australia. They make up what is known as the Great Barrier Reef.

Since the depth of water over continental shelves is not excessive in most places, it is generally possible to exploit any mineral wealth that may exist there. Already petroleum has been extracted in great quantities from continental shelves below the Caribbean Sea and the Persian Gulf. Continental shelves in other areas also contain vast reservoirs of petroleum. A large part of the world's future oil supply will probably come from the sea.

THE CONTINENTAL SLOPES

If there were no oceans and we could view the globe from the surface of the moon, one very impressive feature would be the great slopes that lead down from the continental shelves to the deep ocean floors. These slopes extend from 120 meters below sea level to depths of 11 kilometers.

The continental slopes include some precipices, but in most places they are relatively gentle. They may be compared to the sides of mountain ranges. Some slopes are quite smooth. Others are creased with canyons. Irregularities on the slopes are more pronounced in the upper portions than they are at depths of a kilometer or more. At such depths, the bottom becomes rolling with hills and basins.

The submarine canyons that cut into these slopes also penetrate the continental shelves. The best-known of the undersea canyons are located along the coasts of California, Baja California, the French Riviera, and eastern Japan. These valleys of the sea floor have been surveyed. They have been photographed by lowering incased cameras into their depths. A few have been explored by divers and aqualung swimmers. Investigators have dredged rocks from these canyons. They have measured their bottom currents and have even detected the existence of slow landslides within them. So little has been left to guesswork that we can describe these canyons with accuracy.

One lies off the Scripps Institution of Oceanography, at La Jolla, California. Known as the Scripps Canyon, it is essentially a gorge, like those cut by mountain torrents. The heads of Scripps Canyon have been extensively explored by aqualung divers, who have found narrow gorges with vertical or even overhanging walls. The floors of the gorges fill rapidly with sand and sea-plant refuse. These materials slide and flow out of the gorges from time to time, scouring the walls as they move seaward, and this scouring action has produced the overhang in various places.

The walls of the gorges must closely resemble the sea cliffs along the shore in this area. Here and there the canyon floor is so narrow that it is practically a "fat man's misery," such as is found in narrow gorges on land.

Another fascinating canyon, the Monterey, in Monterey Bay, California, has a large tributary into Carmel Bay. Like Scripps Canyon, Monterey Canyon and its Carmel tributary can be traced almost to the shore.

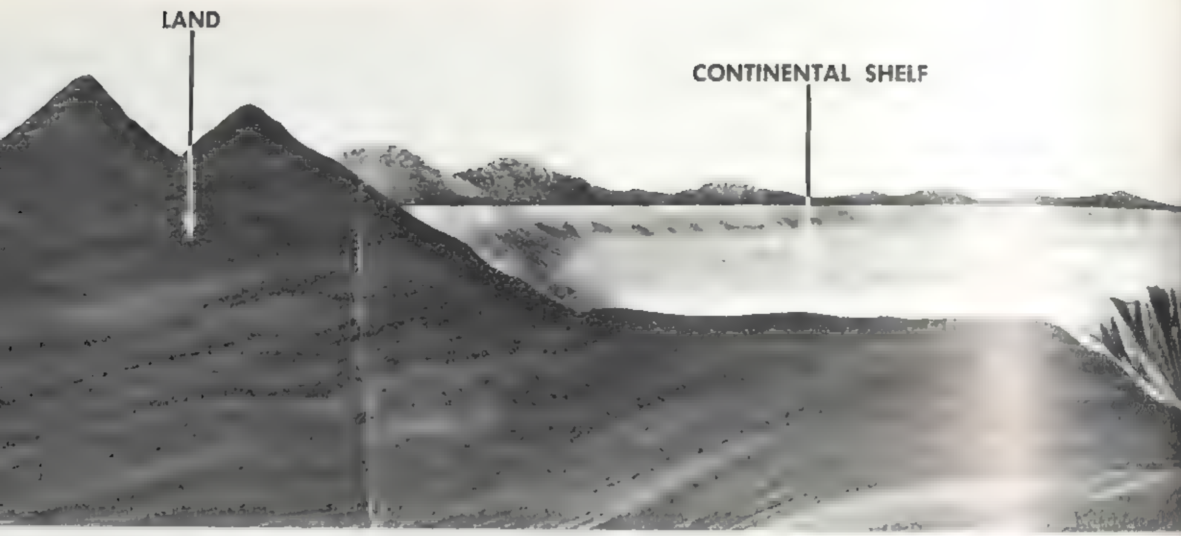
Scripps and Monterey canyons strikingly resemble land canyons. They are V-shaped in cross section; their floors slope outward continuously; they have tributaries; and they are cut into the rocks of the earth's crust. Monterey Canyon has a twisting course and many tributaries. What is more natural than to assume that the submarine canyons were cut by rivers?

Rivers cannot erode the ocean bed

Aerial photograph of the Pacific Ocean, taken by the Gemini 5 astronauts. The water is clear enough to see some bottom contours. White puffs are clouds.

when they enter the ocean, since the comparatively light river water flows out over the surface of the heavy salt water of the ocean. How, then, could rivers cut canyons on the sea floor? The most obvious explanation is that the submarine slopes were once not covered with water. Therefore, rivers could flow down them and carve out canyons, just as rivers cut canyons on the sides of mountains today.

Other theories have been proposed. According to one of these, the carving agency is heavy, sediment-laden water coursing down the submarine slopes and forming currents known as *turbidity currents*. The finding of sand layers on the deep floors of the canyons and even out on the ocean bottom beyond them gives some support to the turbidity current theory. The



Above: continental shelf, continental slope, and ocean floor form the three major provinces, or areas, of the vast ocean bed. Right: ...tic Ocean bed in profile. Note the Atlantic Ridge, running roughly parallel ... coasts

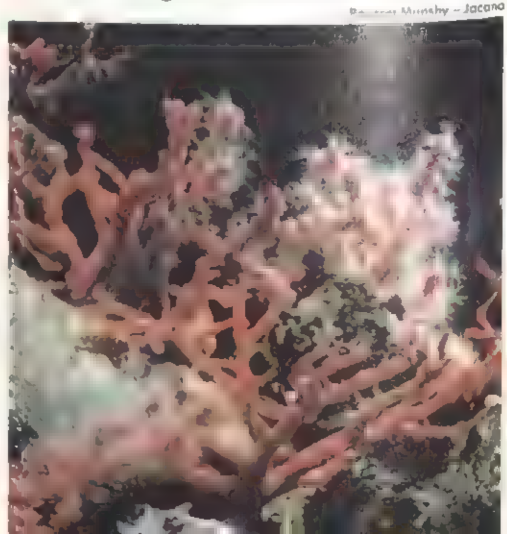
breaking of cables after earthquakes has also been attributed to turbidity currents. After the Great Banks earthquake of 1929, 12 cables in the area were broken in 28 separate places. The cable breaks occurred, one after the other, moving outward, perhaps indicating that turbidity currents can sometimes flow at high speed.

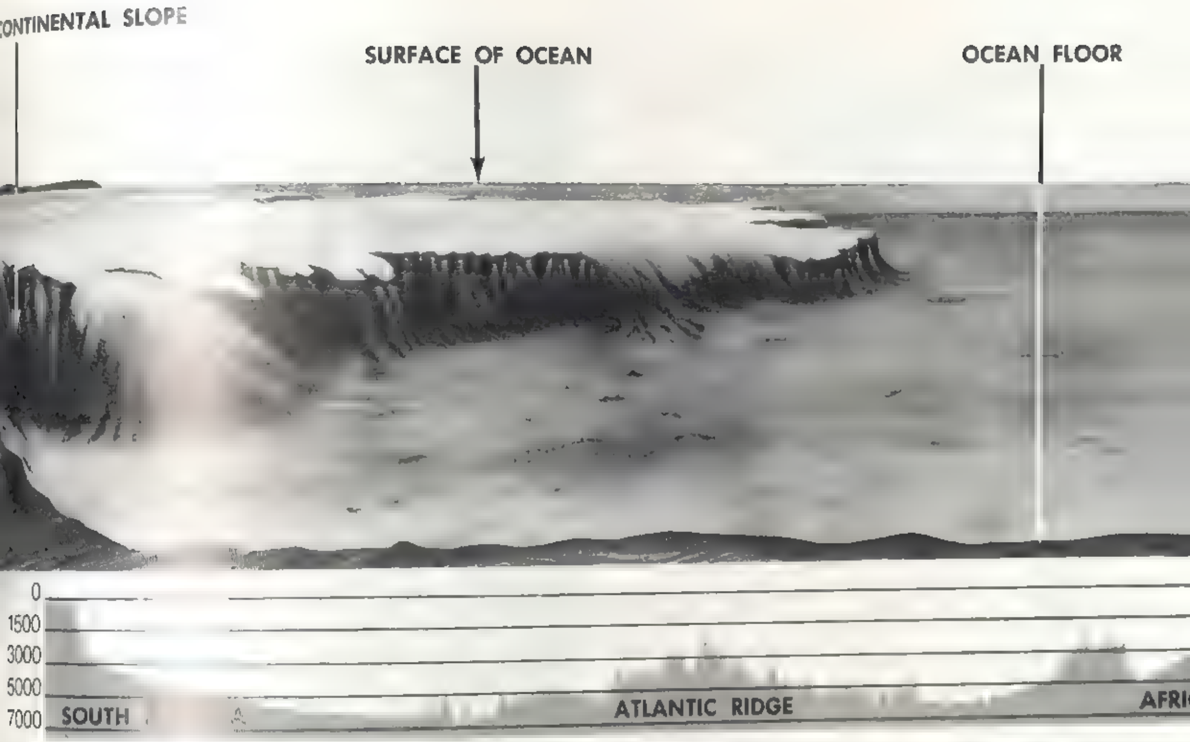
THE TRENCHES

At the base of the continental slopes lining the Pacific Ocean there are deep, narrow depressions known as *trenches*. High ridges mark the oceanside boundaries of these trenches. Within the trenches are found the greatest depths of the sea. The deepest measurement made—11,033 meters—was taken in Mariana Trench east of the Mariana Islands. This is deeper by far than the height of the world's tallest mountains. Yet men have explored these depths. In January 1960, the French oceanographer Jacques Piccard, together with U.S. Navy Lieutenant David Walsh, took the bathyscaphe *Trieste* to the bottom of the Mariana Trench.

Almost as great depths have been found in the Tonga Trench near the Tonga Islands, in the Mindanao Trench in the Philippine Archipelago, and off the southern islands of Japan. There are also deep trenches in the Atlantic Ocean, such as the Puerto Rico Trench north of the islands of Haiti and Puerto Rico, and the South Sandwich Trench to the east of the South Sandwich Islands. In the Indian Ocean there is a trench parallel to the southwestern coasts of Java and Sumatra.

The deep-sea trenches lie in a zone of earthquake and volcanic activity that extends around the world. Also part of this zone are the great mountain chains on the

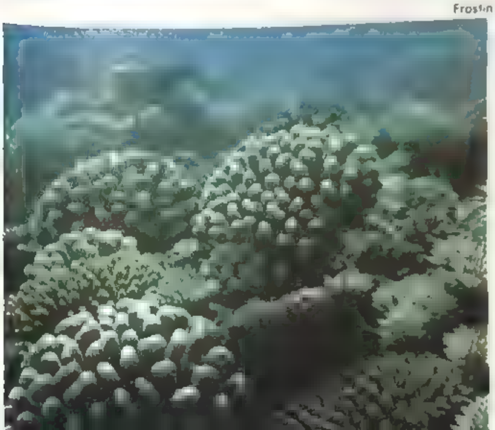




continents—the Rocky Mountain-Andes chain and the chain that extends from the Alps in Europe to the Himalayas in Asia. In addition, the earthquake zone includes the mid-ocean ridges that are described in the following section. It is more than a coincidence that all of these large-scale features of the earth's surface are linked in this way. Many scientists believe that these features can be explained in terms of the theory of continental drift, which holds that the earth's large landmasses are steadily shifting. Ocean-floor studies related to the theory of continental drift are of great current interest.

Coral, below and at left, builds up coral reefs along the edges of continental shelves in many tropical areas

Frostin



THE OCEAN FLOOR

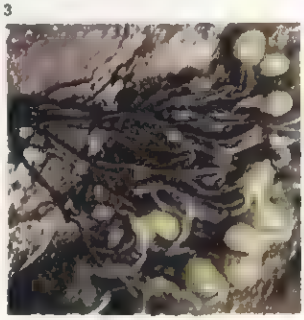
The vast ocean floor covers almost two thirds of the earth. Its average depth is 4,000 meters, but there are great variations in depth because the ocean floor is often very rugged. The ocean floor is made up of wide and sloping plains, great basins, long ridge systems, and many large mountains. Some of the mountains extend above the surface as islands.

The ocean floor at the base of a typical continental slope continues to descend seaward, but at a much more gentle rate. This region is known as a *continental rise*. It is sometimes a few hundred kilometers wide. The floor then levels out into a very flat, sediment-filled plain known as an *abyssal plain*. The Atlantic Ocean bottom has many abyssal plains, whereas corresponding regions of the Pacific Ocean bottom are often hilly.

Beyond the abyssal plains are the great ocean deeps. These are large, generally oval-shaped basins with gently sloping


1


2

3


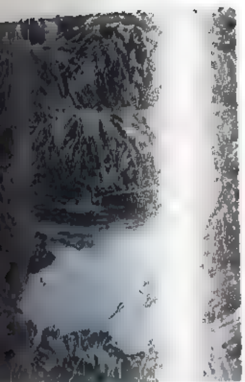
4


sides. Such basins make up about one third of the Atlantic and Indian Ocean floors and about three fourths of the Pacific floor.

The rest of the ocean floor consists of a system of high ridges. The ridges are 1,000 to 4,000 kilometers wide and rise to a height of 2 to 4 kilometers above the bottom. At some places the ridges extend above the sea surface. Iceland, for example, is a part of the mid-Atlantic ridge that extends down the middle of the entire Atlantic Ocean. A rift valley that is the site of much earthquake and volcanic activity runs along the center of this great ridge. The ridge is crossed by many parallel cracks, or fractures, in the ocean floor. Each fracture in the ocean floor may extend for many hundreds of kilometers.

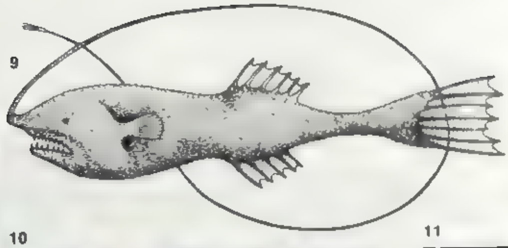
Another great ridge-and-fracture system begins near the western coast of North America and extends across the Pacific Ocean toward the Antarctic coast south of New Zealand. This ridge connects with a ridge running south of Australia. One branch of the ridge south of Australia extends into the Indian Ocean, and another branch runs south of Africa to line up with the mid-Atlantic ridge. As said before, this worldwide system of ridges plays an important part in the theory of continental drift. Research vessels are being sent down to great ocean depths to explore these underwater mountains and connecting ridge-and-fracture systems.

Another kind of elevation found in the ocean is the *seamount*. A seamount is really an isolated mountain peak of volcanic origin. Some seamounts, particularly in the Pacific, have flat tops. These are called *guyots*. One of the largest known guyots lies to the north of Midway Island. It is 4,570 meters high, 72.5 kilometers wide, and 112.5 kilometers long. Long ago it reached the surface of the ocean, and its top



6

9

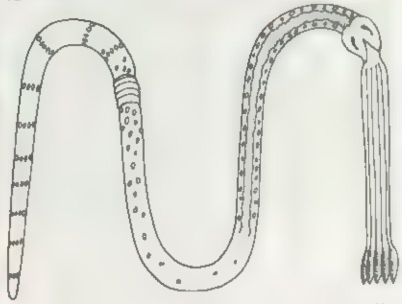


10

11

8

12



1, 5, Chaumeton-Jacana, 2, Photo Researchers, 3,7,8,9, J. Six; 4, R. Decottignies-Jacana, 6. R. H. Noailles, 11, W. John-Doc. Eastman Kodak Co

The types of plants and animals encountered in the sea varies with depth. In zone 1 (diagram at far left) lichens (1) and gastropods (2) can be found. Zone 2 inhabitants may include a *Fucus* alga (3), and mussels (4). The 3rd zone may be a home for *Zostera* grass (5) and for sea anemones (6). Red algae (7) and sponges (8) are characteristic of zone 4 Fishes like *Gigantactis macronema* (9) live in zone 5, together with madrepores, or stony corals (10). In the 6th zone, curious creatures like *Umbellina* (11) may be found. Pogonophores (12), animals with long tentacles, occupy the deepest zone, 7

formed an atoll. Later it became submerged, and it now lies 460 meters below the surface. Many other such hidden giants exist.

ATOLLS AND CORAL REEFS

Among the most interesting structures rising from the ocean floor are the *atolls*—partially submerged coral reefs that form rings of low islands around large, roughly elliptical lagoons. The ordinary atoll has a characteristic profile, standing partly above and partly below the level of the sea. There is an inner lagoon with depths averaging 50 meters but full of slightly submerged pinnacles on which masses of coral are rising.

The great naturalist Charles Darwin proposed an ingenious theory to account for the formation of atolls and of barrier reefs, too. Both types of reefs, he thought, were originally fringing reefs growing off the shores of volcanic islands. In time the islands sank into the sea so that only the central portions remained above water. The fringing reefs grew up toward the surface, leaving a lagoon between the reef and the island. In this way a barrier reef was created. If the island were completely submerged, the growing reef would form an atoll—a ring with a lagoon in the center.

The American geologist Reginald A. Daly offered a quite different explanation. It was based on the idea that the sea level was lowered a hundred or more meters during the period when huge glaciers were carving the land. He held that the water became cold and muddy when glaciation was taking place and that the reef-building organisms died.

The waves would cut terraces in the sides of the islands at the low sea levels that existed at that time. When the glaciers began to disappear and the climate grew warmer, the reef-building organisms would return. Establishing themselves on the outside of the terraces cut by the waves, they would grow upward, keeping pace with the gradually rising sea level. In this way, barrier reefs would be formed where the islands had been only partly eroded by the waves. Atolls would arise where the waves had completely cut across the island leaving only a submerged platform.

That Darwin's hypothesis is essentially the correct one has been definitely shown in recent years (1) by drillings made in two atolls—Bikini and Eniwetok, of the Marshall Island group—and (2) by extensive studies of the basements of coral atolls by geophysical methods. The drillings at Eniwetok have revealed over 1,220 meters of reef coral overlying an old volcanic platform. After the volcano ceased erupting, some 80,000,000 years ago, it was partly eroded by the waves and then slowly sank, going down at a rate that allowed the coral to grow upward apace with the sinking. The oldest corals grew about 60,000,000 years ago and they have been covered by successively younger formations. Since coral reefs grow only in shallow water, the island platform was never deeply submerged. It seems likely from various other borings that this method of atoll formation has applied to most of the other atolls and coral banks in the southwest Pacific.

Although sinking of the land has been the principal cause of atoll formation, sea-level lowering accompanied by wave erosion has undoubtedly had an effect upon islands and continental coasts alike. If the sea should some day reach the level it had before there were ice caps, the coral islands would no longer rise above the surface of the ocean and land-dwelling creatures would die. The same sea-level rise would cause the great centers of population along the coasts of the world to become submerged.

The rising level of the ocean would be brought about by the melting of the ice caps. However, unless man were to eliminate the caps with nuclear blasts, the melting process would be so slow that future generations of mankind would easily be able to adjust to changing conditions.

Maylin

A fringing reef in the south Pacific. Fringing reefs are built up by colonies of coral around coastlines in tropical waters

G. E. Ocean Systems Projects

The ocear ' -p, blue, and teeming with a great variety of life forms — is man's last front e ...man beings are just beginning to explore the depths of the sea

DEEP-SEA EXPLORATION

by Paul J. Fox

Through the centuries, man has conquered, inhabited, and studied some of the harshest environments on the earth's continents. The oceans, however, which cover about 70 per cent of the surface of our world, have not yielded so easily to man's curiosity. In many ways, we know more about outer space than about the great ocean deeps.

Deep-sea exploration, as the name indicates, is concerned with the ocean and its floor and life-forms at great depths. More specifically, it deals with the sea beyond the edges of the continental shelves to depths of 180 meters and more. The entire mass of water in this region, however, from the surface down to the greatest known depth of 11 kilometers, is also included in the subject.

A tremendous variety of methods and instruments is used to investigate the sea and the ocean basins. The one device that is virtually indispensable for most forms of marine exploration today is the oceanographic ship. The first part of this article deals with the oceanographic ship, its equipment, and some of the scientific results of its use. The second part of the article

Les Requins Associes

The effects of prolonged activity underwater have been investigated in several experiments. Here, a diver leaves his undersea home to do research.

takes up special oceanographic research that requires far more than the oceanographic vessel and its apparatus.

OCEANOGRAPHIC SHIPS AND EQUIPMENT

The oceanographic ship provides a platform upon which scientists collect data from the ocean. It contains laboratory space for biological, chemical, geological, geophysical, and meteorological (weather) investigations. There is ample deck room for oceanographic equipment and instruments. All ships have large winches capable of holding several kilometers of strong cable, which is used to lower oceanographic devices to the floor of the ocean.

A typical oceanographic ship is generally not large, averaging a few thousand metric tons displacement, and is about the size of a small freighter. There is typically a small crew, and also a number of scientists on the ship.

An oceanographic vessel at sea operates in two modes: the *underway mode* and the *on-station mode*. During the underway mode the ship moves slowly at 10 to 20 kilometers per hour and measures various properties of the ocean and its floor continuously with various instruments. During the on-station mode, the ship may not move at all. Properties of the sea that cannot be measured continuously are determined by means of various sophisticated devices and techniques.

SHIP'S UNDERWAY OPERATIONS

While an oceanographic ship is underway, it studies sea depths, the nature of bottom layers as determined by seismic (quake) recordings, and gravity and magnetic patterns.

DETERMINING OCEAN DEPTH

Before the early part of the twentieth century, the only known method of determining the depth of the sea at any point was by means of a cable. The ship stopped and a hemp line or wire with a weight at the end was lowered to the bottom. This was a slow, laborious task and not very accurate.

In 1911 an engineer devised a method of determining depths from a moving ship by means of sound pulses. The time required for a sound pulse to travel from the ship to the bottom, from which it was reflected, and back to the ship was measured. Since the velocity of sound waves in seawater is known, the depth of the ocean at that point can be easily determined. This system is known as *echo sounding* or *echo ranging*. Later, a continuous echo-ranging method was developed.

The echo sounder uses a pinger mounted abroad the ship below the waterline. It releases the sound pulse. The echo is picked up later by the ship through a sensitive underwater microphone called a hydrophone. The hydrophone converts the sound pulse into an electrical signal, which is then recorded on a continuously moving chart. As the ship sails along, a topographic profile of the bottom is traced on the chart through a series of signals.

Echo sounding has shown that the bottom of the sea is not predominantly flat, as was once believed. On the contrary, its topography may be as rugged and as varied as that of the continents. Jagged mountain ranges, steep valleys, and flat plains are found in all the major ocean basins of the world.

A continuous series of mountainous ridges and associated rifts, the so-called Mid-Oceanic Ridge, extends through the Atlantic, Indian, Arctic, Antarctic, and South Pacific oceans and the Norwegian Sea for a total distance of over 55,000 kilo-

meters. The deepest parts of the ocean floor (down to 1[illegible] kilometers) occur as linear or arc-shaped trenches not far off certain coasts of the continents and island chains.

STUDYING BOTTOM LAYERS

The method described above simply gives water depths. It says nothing about the kinds of rocks and other deposits, their thickness and structure, underlying the base of the water itself. One technique that reveals the layers in the ocean floor is seismic, or earthquake, surveying.

The quakes that are studied are not natural quakes, but rather are relatively weak vibrations that are induced in the ocean floor by explosions or other intense manmade sounds propagated in the seawater or in the bottom. These sound waves, as they pass through the rocks of the sea floor, are reflected off certain layers or are refracted, or bent, by others. These waves are received back aboard ship through hydrophones as electric signals that are recorded. Refraction surveying uses refracted quake waves; reflection surveying uses reflected quake waves.

The oceanographer measures the total times it takes for the sound waves to travel from their origin to the hydrophones. From this and with ordinary geometric reasoning the paths of the sound waves can be traced. By recording either a line of explosions at one fixed receiving position or a single shot along a line of receiving positions, a relationship of sound-travel times to distances from the explosion site can be established. This information enables oceanographers to determine the number and thickness of layers in the ocean bottom.

Also, the velocity of sound propagation through a given layer can be determined. This figure enables the oceanographer or seismologist to infer the kinds of material making up the ocean layer being studied.

One of the most important discoveries of seismic surveying has been that the earth's crust underlying the oceans is much thinner than that portion underlying the continents. The average thickness of oceanic crust is about 10 kilometers; that of the continental crust is about 30 kilometers.

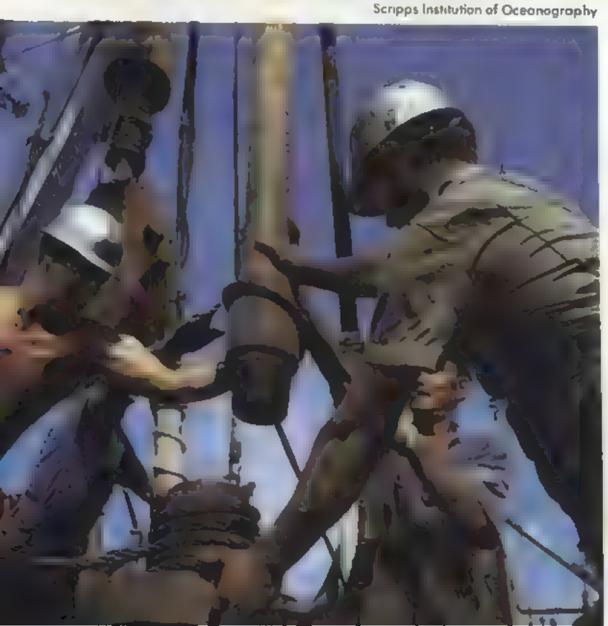
Moreover, the oceanic crust is remarkably similar in different oceans. Three crustal layers are almost always present underneath the sea. The uppermost, *Layer 1*, often consists of loose deposits called *sediments*. It is 0.1 to 4 kilometers thick. The velocity of sound waves in Layer 1 is from one to two kilometers per second. This layer is thicker near the margins of the continents because the continents supply sediments in enormous volumes to the adjoining deep ocean basins.

On the crests and flanks of the mid-oceanic ridges, Layer 1 is unusually thin, only 0.1 to 0.5 kilometer. This fact has led many oceanographers to propose that the ocean basins are growing steadily wider around the ridges and that the crests of the ridges are the youngest portions of the basins.

Layer 2 ranges in thickness from one to four kilometers. The velocity of sound waves in it is 4 to 5.5 kilometers per second. It appears to be composed of sedi-

Several missions have sent human beings to live in the sea for varying periods of time. Here, a craft that will house divers and scientists is launched

Scripps Institution of Oceanography



ments and solid rocks, consisting of any combination of the following: limestone, sandstone, basalt, metamorphic rock, or silica. Most investigators believe that basalt, a dark, dense rock of volcanic origin, is the most abundant.

Layer 3, the lowermost and often called the oceanic layer because it is identified in all ocean basins, ranges in thickness from 4.5 to 5.5 kilometers. The velocity of sound waves in it is 6.7 kilometers per second. The composition of this layer is not known, but it may be gabbro or diabase, rocks related to basalt.

Underneath Layer 3 is the earth's mantle, which is the part of the interior of our planet that lies between the crust above and the heavy core of the earth below. Waves traveling in the upper part of the mantle have a velocity of 8.2 kilometers per second.

Thus far, we have measured such physical properties of the ocean and of the underlying crust as depth and the velocities of sound waves in these mediums. In both cases the oceanographers had to create a disturbance in the waters and the earth to determine these properties. Other instruments are more passive in that they simply measure some energy or force in the earth and the sea that is already there. These forces are magnetism and gravity.

SURVEYING MAGNETISM

The earth's magnetic field converges at the north and south magnetic poles. Sensitive instruments have been devised that not only measure the different properties of the field but that also detect very small changes and variations in it. This procedure not only gives information about the magnetism of local rock masses. Rocks and minerals are often affected by magnetism, becoming polarized like the earth itself or like an ordinary permanent magnet.

Magnetic studies of the earth and the

The *Glomar Challenger* has been involved in several deep-sea drilling projects. Top: art showing how sonar helps keep the Glomar Challenger in position as the drill penetrates the ocean floor. Bottom: drilling crews assemble the needed tools.

sea have revealed that the entire field can suddenly change its polarity—that is, the north magnetic pole can become a south magnetic pole and vice versa.

If a molten rock mass is solidifying, it acquires the polarity of the existing magnetic field of the earth. It retains that polarity ever afterward, no matter how often the earth's field changes its polarity, or direction. In other words, a rock may preserve the record of a former magnetic field of the earth. This condition is called *paleomagnetism* and is frequently studied by scientists for clues to the past history of our globe.

From magnetic studies at sea, geophysicists have discovered that the magnetic anomalies, or irregularities, of the ocean basins tend to occur in narrow belts. They are symmetrical with respect to the mid-oceanic ridges. Lines of anomalies occur parallel to a ridge on each side of it. This suggested to some geologists that thin vertical layers of once molten rock, pushed up through crustal breaks along the rifts, could be the cause of the striplike anomalies.

From their understanding of past magnetic fields, two British oceanographers in the early 1960s proposed that new crustal material, originating in the upper mantle, is injected continuously along the axis of a mid-ocean ridge through the rift associated with the ridge. The molten rock, as it solidifies, acquires the polarity of the earth's magnetic field that was present at the time of injection. Since the earth's field reverses polarity periodically, a sequence of rock strips alternately magnetized in opposite directions is found lying parallel to the ridge axis and on each side of it.

The youngest rocks are closest to the ridge, on each side. From the dating of the rocks and the sequence of magnetic reversals, geophysicists have been able to determine that new ocean floor is being formed at each ridge and moving away from the latter on both sides.

SURVEYING GRAVITY

The methods of gravimetric surveying, or measurement of the earth's gravitational field, are similar to those used in magnetic surveys. There are local variations in the

Ron Church, PR

Deep-Star 4000, a sophisticated submersible craft that can dive to 1,200 meters to study ocean waters and the sea floor.

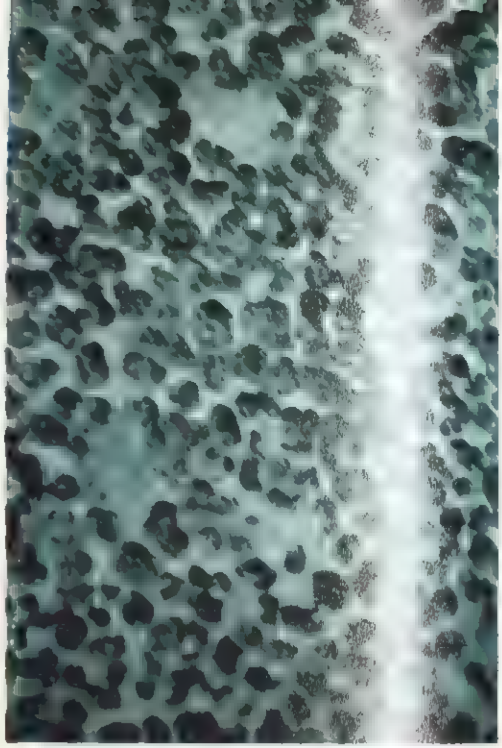
strength of the gravitational field owing to differences in the densities of the various rocks that make up the earth. The effects of the earth's general gravitational field are subtracted, and the remaining readings indicate the anomalies due to local or regional rock masses. Dense rocks have high anomalies; less-dense ones have low anomalies. Even the absence of any considerable rock formations gives low or negative gravimetric readings.

The typical gravimeter in use today aboard ships consists basically of a spring supporting a weight. Changes in the extension of the spring indicate changes in gravitational attraction at that location. Since the earth's dense core surrounds the center of gravity in our planet, increase in distance from this center weakens the pull of gravity on any body.

Gravimetric surveys of the oceans have

Deepsea Ventures, Inc., a subsidiary of Tenneco, Inc. Photos by B.J. Nixon

The ocean floor is being prospected for mineral ores. Special cameras, such as the one above, scan the sea floor to locate mineral deposits.



Manganese nodules are formed in place on the ocean floor. Some areas are strewn with millions of these deposits, which are an important resource.

shown that the ocean basins are generally in balance with the continental masses. What this actually means is that the mass of a given column of continental crust balances the mass of a given column of oceanic crust plus the overlying column of water. General crustal balance is called *isostasy*.

Oceanographers have found, however, that there are striking departures from isostatic balance in some areas of the ocean basins. Strong negative gravity anomalies, pointing to deficiencies in the mass of the rocks, have been detected in surveys over the deep ocean trenches mentioned earlier in this article. These trenches border most of the Pacific coastlines and the island arcs.

Most scientists believe that the trenches represent long, linear zones of compression, where the crust is being buckled down into the underlying mantle. The forces causing this are thought to be related to those widening the ocean basins and thinning the crust at the mid-ocean ridges. In other words, the ridges are places where crust is being formed, while the trenches are places where crust is being destroyed.

The methods of oceanographic surveying described above are used during the underway mode, while the ship is moving. The following discussion of oceanographic techniques and some of their results centers on those employed during the on-station mode, when the ship is often stopped.

ON-STATION MODE OPERATIONS

Oceanographers must find out about the ocean water itself and also about the rocks and sediments on the sea bottom in contact with the water. The underway-mode type of operations gives relatively little information about these factors.

Since ocean depths range from 100 to 11,000 meters, oceanographers have designed specialized items of equipment capable of collecting data to extreme depths. They are lowered by cable to any point under the sea surface. Most oceanographic ships stop once or several times a day to "take a station". That is, they stop to take measurements and samples while station-

ary. These measurements and samples are of various kinds.

DREDGING AND TRAWLING

Among the first tools developed by oceanographers were trawling and dredging devices to take specimens of marine life and sediments and rocks from the sea floor.

Trawls Trawls are for biological work and are of two types. One has an iron rectangular frame to which a ridged mesh bag of iron is attached. The trawl is lowered by wire cable to the bottom. Then the ship is moved ahead slowly for a short distance, enough to catch some marine organisms in the bag as it drags along the bottom.

The second type of trawl has a bag of woven nylon attached to the frame. This trawl is pulled only through the water at a selected depth by the ship, and nets specimens of sea life.

Trawl sampling has revealed the presence of life in most depths and regions of the ocean. Marine organisms, both animal and vegetable, are usually concentrated in the uppermost several hundred meters of the ocean, where most of the sunlight and food materials are. Nevertheless, some animals have adapted to living in the extreme pressures and dark cold of the deepest oceanic abysses.

Dredges Dredges are used to obtain samples of rock and sediments from the bottom of the ocean. To collect large volumes of sediment, oceanographers use a dredge called a *grab sampler*. This device resembles a large, box-shaped clam. When lowered to the bottom and triggered, the jaws of the sampler close suddenly and scoop up a sample of bottom material.

Dredges for sampling hard rocks make use of a large iron-link bag attached to a steel rectangular "mouth." The dredge is lowered by a strong cable to the sea floor, but only where hard rocks are not covered by deep layers of sediment, as on steep slopes where sediment cannot accumulate. The dredge is dragged by the ship. It breaks off edges of rocks and catches them.

Work with dredges shows that much of the ocean bottom the world over is covered by layers of mud and ooze, some of it very deep. This sediment is composed of land-derived material, the minute shells of sea organisms, and meteoritc dust. The solid rock is commonly basalt or related igneous rocks, as well as metamorphic rocks and hardened sedimentary rocks.

The mid-oceanic ridges along their crests are composed of basalts and metamorphosed igneous rocks. Many of these have been dated by radioactivity measurement and have been found to be young by geologic standards—1,000,000 to 10,000,000 years.

Igneous rocks dredged from the flanks of the crest are markedly older—50,000,000 to 100,000,000 years. This situation confirms the theory that the ridges are the sites of new crust formation and that the crust moves away very slowly from both sides of a ridge. In fact, the greatest known age of any oceanic rock is about 170,000,000 years. Some continental rocks are well over 3,000,000,000 years old. The present ocean basins, then, are much younger than the continents.

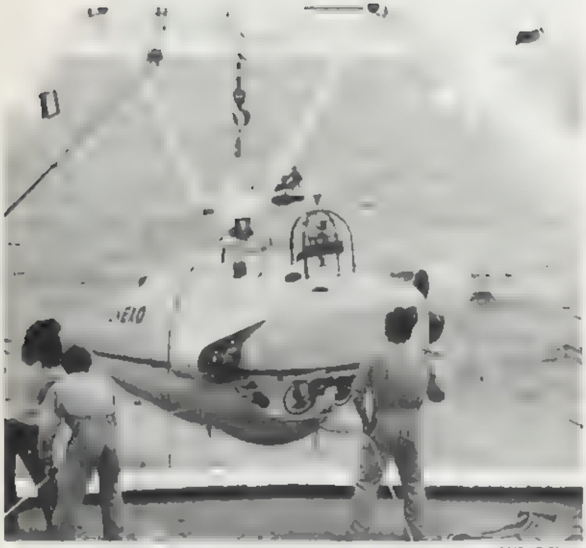
Dredging is a rather crude method of sampling the ocean bottom. It disturbs the rocks and sediments so much that oceanographers may not be able to get an exact idea of what they have obtained and where it came from. They would much rather get small cross sections of as much of the bottom as possible. In other words, a device such as a tube that goes down vertically into the mud and rock and extracts a long *core* preserving all the essential features of the material is far more preferable.

CORING

Short coring devices were first developed in the late 1800s. Improvements in later years, such as explosive charges, triggering mechansims, and pistons inside the tubes, have produced very long cores 10 to 30 meters in length.

After a core is taken on deck, it is extracted from the tube intact. It may be studied aboard ship or stored in a container for transportation to a land-based laboratory for future examination.

A core is packed with a tremendous



CNEXO Photo

The *Cyana*, a submersible vessel of French design and construction, was involved in Project FAMOUS. Submersible craft have greatly helped deep-sea research

amount of information for the specialists who examine it. They probe it microscopically, chemically, and physically. Any layering in the core reveals the history of the sediments and rocks of the sea bottom. Age analysis dates the core and also gives the rate at which the sediments composing it have accumulated. It may have taken millions of years for a few centimeters of mud to collect, for example. If possible, the history of the ocean bottom and of the sea itself that is exposed by analysis of a bottom core is correlated with geological events thought to have occurred in the history of the continents.

Geologists can tell about former current patterns and the temperature and salinity changes the oceans underwent in the past by studying the chemical constituents of the rocks and sediments in a core. The shells of small long-dead plants and animals in the core also tell a similar story. For example, from these core contents geologists have worked out the temperature changes in the ocean that took place as the glaciers advanced and retreated on the continents during the last Ice Age, up to 2,000,000 years ago.

HEAT FLOW MEASUREMENTS

The temperatures in the ocean are caused not only by climate and weather and by the ocean's own internal conditions, but also by the flow of heat from the earth's interior. Heat flow also reveals the state of the earth itself at any point. Instruments to measure this heat flow have been devised and are used in oceanographic work also.

Much of the earth's heat energy originates in the interior. It is generated by the extreme pressures in the interior and also by the energy of radioactive mineral concentrations at various spots. Much of this heat energy eventually escapes through the crust and the surface. In general, heat flow from the earth is uniform for land and sea, but there are significant variations.

Information about heat flow enables geologists and oceanographers to draw conclusions about the amount and distribution of heat sources in the earth and about the thermal history of our planet

Two measurements must be taken to calculate heat flow: the range of temperatures (temperature gradient) and the heat conductivity. These measurements are taken on cores extracted from the ocean floor. Electrical instruments mounted on the coring device give the temperature gradient at different positions on the core. When the core is extracted on deck, heat-conductivity determinations are made. Temperature gradient and heat conductivity, when multiplied together, give the heat flow through a given standard area of the ocean floor.

From numerous heat-flow measurements it has been found that in general the heat flow per unit area of the ocean floor is nearly equal to that through each unit area of the continents. High values of heat flow, however, exist along the axes of the mid-ocean ridges. This probably means that hot molten rock matter is being pushed up from inside the earth along the crustal ridges.

All the methods described above do not give an actual picture of the sea bottom, but only certain of its properties. But scientists would like to see what is down there, if they cannot actually go themselves. Photography of the sea floor is one answer.

SEA-FLOOR PHOTOGRAPHY

The techniques for extensive photography of the ocean bottom has been perfected in recent years. Strong, watertight cameras capable of operating almost continuously at great depths have provided oceanographers with numerous photographs of the bed of the ocean. Now scientists can study the distribution and kinds of life far below the surface of the sea, as well as the rocks, sediments, forms of erosion, and the patterns of current-ripple marks and other kinds of water markings on the bottom. Today's deep-sea cameras can take many pictures in a single lowering to the sea floor.

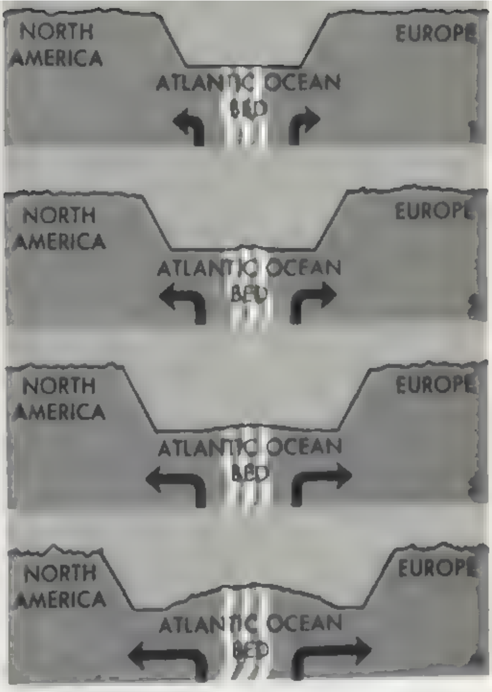
Many photographs of the sea bottom have shown that animal life exists at the greatest depths. Some of these organisms represent newly discovered species. In many areas the deep-ocean floor is marked by the action of powerful currents whose existence was hardly suspected before.

WATER SAMPLING

Many of the oceanographic methods thus far described have dealt with the bottom, rocks, sediments, and life of the ocean. The water itself and its properties, of course, are highly important in oceanography. These properties include its transparency, its content of mineral and organic matter, temperatures, salinities, pressures, currents, waves, and so on.

Oceanographers take samples of seawater at many localities and depths in order to measure many of the properties mentioned above. They use special containers called *water samplers* for this task. The latest types are sometimes very large and are made of rubberized nylon. However, most are much smaller. There is a valve at each end of the container.

Several samplers, with valves open, are attached at different levels to a wire cable. They are then lowered into the sea until each sampler reaches the desired depth. Next a series of weights is automatically slid down the wire, closing the valves of the samplers in succession and thus trapping the water that has entered the containers. As this happens, special thermometers at-



The widening of the Atlantic Ocean and the drifting apart of North America and Europe through time. Stage 1 (top) represents a period, about 140,000,000 years ago, when the two continents were much closer. Stage 4 shows positions of Europe and North America nearly 20,000,000 years ago

tached to the samplers record the temperatures of the water samples.

Water-sampling stations determine the temperatures and salinities of the seawater at a given locality. Because of the spacing, however, it is not possible to get detailed readings at all depths in an entire region. Devices that monitor temperature and salinity at all depths are being developed.

CURRENT MEASUREMENT

There are numerous ways of tracking surface and below-surface currents. These involve the use of floating radioactive substances, bottles, and other markers, as well as highly visible dyes.

More sophisticated methods involve the use of special current meters to determine the rates and directions of oceanic currents at the surface and below it. These meters may be used aboard ships or with special buoys, or floats, moored at various spots in the ocean. Neutral-buoyancy floats are set to sink to any desired depth. As they move along, they emit sound signals that

are detected by a research ship's hydrophones. The paths of the floats are thus followed, so that current directions and velocities can be charted.

The result of all this work shows that the ocean is full of complex currents moving in many directions and at various depths. For example, it has been found that a large surface current often has a countercurrent moving along below it, but in the opposite direction.

We have given an idea here of the more-or-less-routine work of an average oceanographic ship. There are other kinds of marine research that require special equipment, such as deep-sea drilling and manned descents to the depths.

MANNED DESCENTS

Man has for a long time desired to see the depths of the ocean for himself. No matter how ingenious his instruments, they are no substitute for going himself for a look. Diving suits allowed men to go down only a hundred meters or so at best. Scuba or skin-diving methods may eventually allow a human being to descend directly for several thousand meters.

But machines have thus far been the best means for men to enter the abyssal realms of the ocean. In the 1940's and 1950's, the Swiss scientist Auguste Piccard developed the bathyscaphe, a deep-diving vehicle that carried its own electric power and air supply. Ballast and buoyancy chambers allowed the vehicle to control its vertical motions. In the first bathyscaphe Piccard and his crew descended nearly 11 kilometers to the bottom of the Marianas Trench in the Pacific, the deepest known ocean trench.

Since that time, a great variety of submersible craft have been designed and built to explore underneath the ocean's surface. The depths to which they can dive depend on the purposes for which they were built. Many of them can travel around and are fully maneuverable at these depths. The craft are equipped with all kinds of devices—lights, cameras, mechanical arms, nets, water samplers, corers, and so on—to explore the bottom of the sea and the ocean waters. Several of these research vessels were used during the international project FAMOUS in the mid-1970's. FAMOUS stands for French-American Mid-Ocean Undersea Study.

Men have also been placed in undersea stations from which they sally forth to study the world underneath the ocean surface. Such stations have been sunk thus far in relatively shallow waters only, but scientists see the day when entire communities of investigators may be settled on the deep-ocean floor. In the Sea Lab experiments of the U.S. Navy in the late 1960's, men and women were sent to live at depths of 180 meters in special chambers on the ocean bottom. From such experiments scientists hope to train human beings to live and do research at great depths.

DEEP-SEA DRILLING

In the 1950's, the idea of actually *drilling* into the deep-ocean bed from the surface was born. Formidable technical problems were later solved, primarily with the knowledge gained through oil drilling offshore.

In 1966 the U.S. Joint Oceanographic Institution for Deep Earth Sampling (JOIDES) was organized. This is a plan for drilling shallow holes into the ocean bed at many places in the world in order to extract cores for scientific study. In 1968 a ship named the *Glomar Challenger* was built basically as a deep-sea drilling platform for this JOIDES project. A dynamic positioning system keeps the ship exactly on the desired location where drilling goes on. The drill can go through as much as six kilometers of water at the end of a series of drill pipes to reach the sea floor. It makes a hole in the bottom and extracts a core.

Since her launching, *Glomar Challenger* has collected cores at sites all around the world. By the early 1980's, the ship had obtained many thousands of meters of sea-floor samples during more than 70 cruises. In 1981 the oldest cores ever recovered—rock about 150 million years old—were drilled from a depth of 1,647 meters beneath the sea floor in water almost five kilometers deep.

THE GEOLOGICAL TIME SCALE

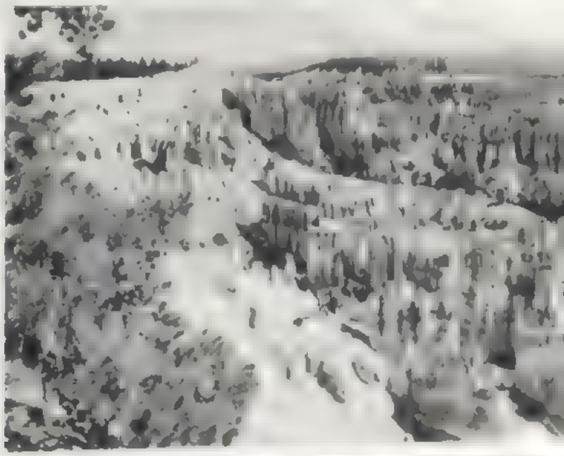
The [illegible] earth and its living things have h[illegible] long history, which has been recorde[illegible] part at least, in certain rocks of the ear[illegible]ust. The name "geologic time" is give[illegible] the long period—hundreds of millions [illegible]ears—that is covered by this rock re[illegible]

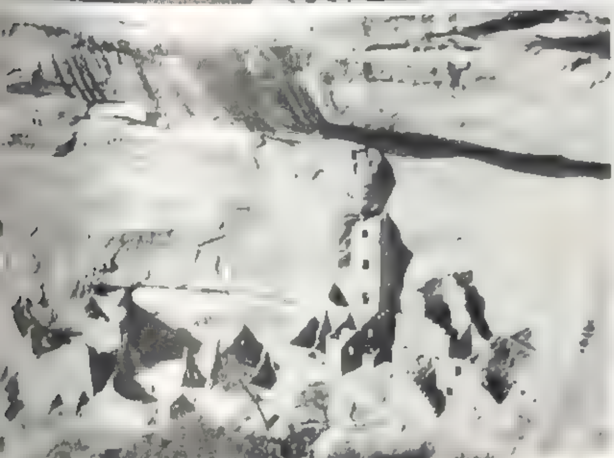
It is based on the fact that the remains of once-living plants and animals are entombed as fossils in various rock formations. In some cases, the fossils are actual remains. In others, they represent the imprints of organisms. Remains and imprints were buried in the successive layers of sand

Geological time made visible. The Grand Canyon's (upper left) lowest rocks date from Pre-Cambrian times. The Canyon's upper rock layers are about the same age as the lowest rocks in Canyonlands (upper right) Canyonlands upper rocks correlate with the lowest rocks in Mesa Verde (bottom left) and Bryce Canyon (bottom right).

U.S. National Park Service, photo by M.W. Williams

U.S. National Park Service, photo by Jack E. Boucher





...onal Park Service

U.S. National Park Service, photo by Cecil W. Stroughton

PRE-CAMBRIAN TIME

600,000,000 Years Ago

BEFORE THE CAMBRIAN PERIOD

Tremendous span of time, divided into a number of eras

Life Forms: Few fossils. Life scanty, limited to the oceans: plants such as bacteria and algae; possibly animals such as sponges, corals, and jellyfish.

Geology and Climate: A number of mountain revolutions and ice ages. Great volcanic activity.

Mineral Deposition: Formation of numerous metallic deposits, especially iron, uranium, gold, copper, and nickel.

Ended by Killarney Revolution, a time of worldwide continental uplift and erosion.

or mud that collected on the bottoms of seas and streams throughout millions of years. In the course of time, the sands and muds, called sediments, hardened into beds of sedimentary rock, the younger layers atop the older ones. However, because of earth movements, rock beds may be tipped over so that the older strata may lie atop the younger ones. Moreover, rocks often appear as scattered and broken outcrops at the earth's surface and so may not even lie in contact with each other. Un[illegible] the rocks have been too greatly alter[illegible]y the

P A L E O Z O I C

600,000,000 Years — 500,000,000 Years

CAMBRIAN PERIOD

[illegible]OVICIAN

"Period of Cambria," the name of ancient Wales

500–600,000,000 years ago

3 epochs: Lower, Middle, Upper

Life Forms: First abundant fossils of shell-bearing marine invertebrates, particularly brachiopods and the arthropodlike trilobites. Most of the major invertebrate groups present. Plants represented by sea algae. No known land life.

Geology and Climate: Continents invaded by narrow seaways. Climate uniformly warm; some glacial action.

Mineral Deposition: Formation of oil, copper, lead, asbestos, marble, and slate

Ended by Green Mountain (Vermont) Disturbance.

Period named after the Ordovices, a people of ancient Wales

425–500,000,000 years ago

3 epochs: Lower, Middle, Upper

Life Forms: Trilobites and brachiopods still numerous. Many other sea invertebrates; thin floating colonies of almost microscopic animals, the graptolites (now extinct); corals; bryozoans (moss animals); mollusks (snails, clams, and squidlike cephalopods); echinoderms (spiny-skinned animals related to modern sea urchins). First known vertebrates: armored jawless fishlike forms inhabiting streams. Plant life mostly sea algae. No true land life.

Geology and Climate: Continents widely flooded by shallow seas. Volcanoes active in eastern North America. Uniformly warm, but possible glacial action in some regions.

Mineral Depostion: Formation of deposits of oil, gas, stone, iron, lead, zinc, manganese, gold, and silica sand.

Ended by Taconic Disturbance in eastern North America.

Period named after the Silures, a people of ancient Britain

405–425,000,000 years ago.

3 epochs: Lower, Middle, Upper

Life Forms: Invertebrates still dominant: large scorpionlike arthropods (eurypterids), echinoderms such as crinoids (sea lilies); coral reefs. Primitive fish in the streams. First true land plants; first true land animals: forms resembling scorpions and millipedes (many-legged "worms"), perhaps air-breathing.

Geology and Climate: Shallow seas flooded the continents. Volcanic activity took place. World climate generally mild, arid in some areas

Mineral Deposition: Formation of iron, salt, oil, gas, and silica sand deposits.

Ended by Caledonian Orogeny in Asia, Europe, Greenland and Alaska

forces acting within the earth, they contain more or less abundant fossil remains.

Plants and animals have changed gradually through evolution during the passage of geologic time. Such evolutionary changes are revealed in the different types of fossils that are found in succeeding rock beds, or strata. A given rock mass is distinguished from earlier and later masses by the types of fossils it contains. The more highly evolved the plant or animal life represented by the fossils, the younger the rock formation in which they are found. By studying the fossils in the rocks, therefore, geologists can determine pretty accurately the sequence of rock formations, called the *geologic*, or *stratigraphic, column.*

ESTABLISHING STANDARDS

Generally speaking, rocks having identical or similar fossils are believed to be roughly of the same age. In various parts of the world, sections of exposed rocks with their characteristic fossils have been adopted as standards, from which the different intervals of geologic time—the geological

ERA

400,000,000 Years

300,000,000 Years

PERIOD | SILURIAN PERIOD | DEVONIAN PERIOD | MISSISSIPPIAN PERIOD | PENNSYLVANIAN PERIOD

"Period of Devon[illegible]n England

345–405,000,000 years ago

3 epochs: Lower, Middle, Upper

Life Forms: Invertebrates: brachiopods common; trilobites and graptolites declining. Many fish: placoderms, ostracoderms, sharks, lobe-fins, lungfish, and bony fish. Appearance of first true land vertebrates—amphibians. Rise of trees, similar to present ferns, horsetails, and club mosses, reproducing by spores. First seed plants (seed ferns).

Geology and Climate: Warm, locally dry.

Mineral Deposition: Formation of oil, gas, coal, and silica sand.

Before actual end of period, Acadian Disturbance in eastern North America. Towards end of period, disturbances in Missouri.

"Period of the Mississippi" or Lower part of Carboniferous ("Coal-bearing period")

320–345,000,000 years ago.

2 epochs: Lower, Upper

Life Forms: Amphibians and possibly the first reptiles, many living on land. Large sharks; many marine invertebrates: crinoids, spiny brachiopods and bryozoans. On land, swamps with forests of trees propagating by spores.

Geology and Climate: Shallow seas sweeping over the continents from time to time. World climate warm, with desert conditions in a number of areas. In eastern North America, the Appalachian area was somewhat disturbed. In Europe, the Paleozoic Alps were beginning to rise.

Mineral Deposition: Formation of coal, oil, gas, lead, zinc, gold, silver, gypsum, rock-salt, and phosphate deposits.

"Period of Pennsylvania" or Upper part of Carboniferous ("Coal-bearing period")

280–320,000,000 years ago

3 epochs: Lower, Middle, Upper

Life Forms: First true reptiles; many amphibians. Great expansion of arthropods: first definite insects, especially huge cockroaches and dragonflies on land; spiders. Land covered by low-lying swamps supporting dense forests of primitive trees resembling the horsetails, scouring rushes, club mosses, and ferns; also seed ferns, cycads, and early cone-bearing trees.

Geology and Climate: Swamps buried by repeated advances of seas on land, forests later becoming converted into extensive coal beds. Uniformly mild and damp, later cooler with local glaciers and deserts.

Mineral Deposition: Formation of coal, oil, gas, clay, and iron deposits

Numerous mountain disturbances all over the world, suggestive of the coming Appalachian Revolution.

time scale—are derived. If a new rock bed or formation is discovered anywhere in the world, stratigraphers—geologists who study rock strata—try to fit it into one or the other of the standard rock sections.

The geological time scale is the result of almost two centuries of work in stratigraphy. It is accepted, but with certain reservations, by qualified stratigraphers. For one thing, as we have seen, it assumes that living things evolved according to a more or less fixed pattern. Yet we know that evolving organisms do not change in the same degree and in the same lengths of time, like clockwork. Another difficulty is that only certain groups of fossils have been used as standards for the geologic scale. Other fossils and rock formations would have given a somewhat different result, perhaps. The attempt to fit all the rocks of the earth exactly into certain standard sections is one of the most difficult tasks confronting geologists.

On the whole, however, the geological time scale gives us a pretty good idea of the sequence of events in the history of the

PALEOZOIC ERA | **MESOZOIC**

300,000,000 Years | 200,000,000 Years

PENNSYLVANIAN PERIOD | **PERMIAN PERIOD** | **TRIASSIC PERIOD** | **JURASSIC PERIOD**

PERMIAN PERIOD

"Period of Perm," in Russia

230–280,000,000 years ago

Life Forms: Many land animals; freshwater fish; amphibians; mammal-like reptiles; insects and related forms. More advanced, hard-boned fish arose. Last of trilobites and many other typical Paleozoic life forms. Spread of cone-bearing trees and trees resembling sago palms (cycads).

Geology and Climate: Seas retreating, continents rising. Volcanic activity extensive. Climate varied, cooling, arid in many places. Extensive ice sheets in Southern Hemisphere.

Mineral Deposition: Formation of deposits of oil, coal, salts, phosphate, copper, and gold.

Ended by climax of Applachian Revolution, lofty mountain ranges being raised all over the world.

TRIASSIC PERIOD

"Period of three-fold division"

181–230,000,000 years ago

3 epochs: Lower, Middle, Upper

Life Forms: Great development of reptiles; early dinosaurs; large amphibians; possibly the first mammals. Trees mainly cycads and ginkgos (maidenhair trees).

Geology and Climate: Continents not too often flooded by seas. Volcanoes active. Mild to subtropical climate, with wet and dry seasons; perhaps deserts existed.

Mineral Deposition: Formation of coal, salts, zinc, and manganese deposits.

Ended by the Palisades Disturbance in eastern North America.

JURASSIC PERIOD

"Period of Jura Mountains," in France

135–181,000,000 years ago

3 epochs: Lower, Middle, Upper

Life Forms: Evolution of many kinds of dinosaurs, giant and pygmy; other reptile types: flying "dragons," "sea serpents," and lizards. First true mammals (primitive egg-laying and marsupial forms); first birds, reptile-like and having teeth. Appearance of frogs and toads. Hugh cephalopods (ammonites and squid-like belemnites) in shallow seas that swept over continents. First flowering plants.

Geology and Climate: Volcanic eruptions. Uniformly warm, with local aridity.

Mineral Deposition: Formation of coal, oil, aluminum, iron, and possibly gold deposits.

Some time before end of period mountains raised in western United States

earth. It enables us to tell whether one event happened before, at the same time as, or after another. In other words, it establishes the relative chronology of the different periods in the earth's history.

Various methods have been used to fix the absolute chronology of the earth's history — that is, to determine just how long ago particular geologic events took place. One of the most satisfactory of these methods is based on the study of the different rates of radioactive change that have occurred in the rocks.

TIME DIVISIONS

Geological time is divided into various intervals. The major units are eras, periods, and epochs, each with its characteristic geographies, climates, and forms of life. There are also various subdivisions, which we have not included.

The names of the major geological time units are derived in certain cases from the places where the standard, or type, rock formations are found, or where those rocks were first noted. Thus, "Permian" comes

ERA | **CENOZOIC ERA**

100,000,000 Years | Present

OD | **CRETACEOUS PERIOD** | **TERTIARY PERIOD** | **QUARTENARY PERIOD**

"Period of chalk"

63–135,000,000 years ago

2 epochs: Lower, Upper

Life Forms: Continued dominance, climax, and finally total extinction of typical Mesozoic life forms, especially many reptile types and all the dinosaurs. First snakes; toothed birds of large size; mammals small. Large marine invertebrates; numerous fish. Flowering plants spread over much of earth, replacing many earlier types of vegetation.

Geology and Climate: Seas flooding continents and depositing chalk (kind of limestone formed by small sea animals). Warm at first, later cool. Climate zones developed, with local deserts and glaciers.

Mineral Deposition: Formation of oil, gas, coal, diamonds, gold, and many other minerals.

The Mesozoic era ended in the Laramide Revolution, a time of continental uplift, erosion, and grand mountain making on a global scale. The chain of the Rockies appeared in western North America.

"Third period"

1–63,000,000 years ago

5 epochs: Paleocene, Eocene, Oligocene, Miocene, Pliocence

Life forms: Rise and dominance of advanced mammals, developing into many different forms. Modernization of many kinds of life, a great number of which have since become extinct. Rise of primates and man's ancestors; giant toothless birds resembling ostriches and emus.

Geology and Climate: Seas flowing over the lands to some extent, but continents assuming more and more modern features. Warm and uniform at first, but gradually cooling and developing worldwide belts.

Mineral Deposition: Formation of many minerals, especially oil, coal, and aluminum deposits.

Ended by worldwide Cascadian Revolution.

"Fourth Period"

0–1,000,000 years ago

2 epochs: Pleistocene, Recent

Life Forms: Appearance of modern forms of life; extinction of many earlier kinds, such as mammoths and mastodons (both elephantlike) and woolly rhinoceroses. Rise of man.

Geology and Climate: Four or more ice ages in Northern Hemisphere, with warm stages in between.

Mineral Depositions: Formation of oil and other minerals.

Cascadian Revolution continued.

U.S. Geological Survey

A geophysicist uses a mass spectrometer to determine the amount of radioactive change in the rock sample. The rock's age can then be estimated.

from Perm, the former name of a district in the Soviet Union. A period may be named after some group of people that once inhabited a region where the rocks of the period in question were first studied or recognized. The name of the Ordovician period stems from the Ordovices, an ancient tribe that lived in that part of Wales where Ordovician rocks are displayed. Other names refer to some characteristic or other of a given time unit. For example, the name "Carboniferous" ("coal-bearing") is given to one of the periods because a great deal of coal (*carbo* in Latin) was formed then. The Paleozoic era ("era of ancient life") is so called because the first abundant accumulation of fossils goes back to that time. Still other names indicate whether a given time division came earlier or later. Thus we speak of the Miocene ("less recent") epoch and the Pliocene ("more recent") epoch.

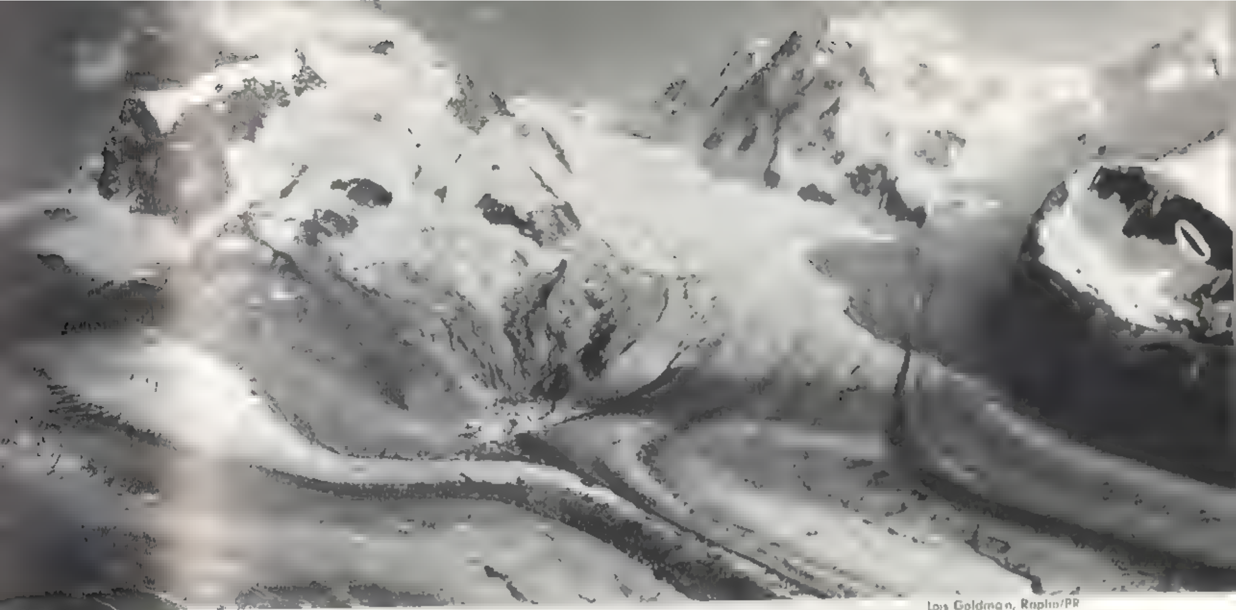
The broadest division of geologic time is the *era*. Each era was ended by a great mountain-making, or orogenic, upheaval, known as a *revolution*. It is evidenced by the intense folding of the rocks and a general break in the rock and fossil record between one era and the next. An era is divided into a number of *periods*. Each of these periods was usually brought to a close by a *disturbance*—mountain-making on a smaller scale—unless it happened to come at the end of the era of which it forms a part. In that case, of course, it ended with a revolution. The mass of rocks belonging to a particular period is called a *system* and bears the same name as the period.

Each period is usually divided into three *epochs*, representing its lower, middle, and upper (early, middle, and late) portions. Epochs often bear distinct names, which vary in different lands. The rocks of an epoch are termed a *series* and carry the epoch name.

Descriptions of the geologic time divisions, with emphasis on events in North America, are given on pages 280–283.

Several radioactive substances and their products can be used to date ancient materials. The chart below lists a few of the most widely used radioactive substances (left column). In a half-life of the substance, one-half of the original amount of the substance will decay, forming a stable daughter product. Analysis of the amount of parent substance and of stable daughter product present in a sample will reveal the age of the sample.

Parent Isotope	*Stable Daughter Product*	*Currently Accepted Half-life Values*
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	713 million years
Thorium-232	Lead-208	14.1 billion years
Rubidium-87	Strontium-87	50.0 billion years
Potassium-40	Argon-40	1.3 billion years



Lois Goldman, Rapho/PR

Glaciers have covered large parts of the earth many times in the geologic past Today they are found in the polar regions and in high mountainous areas The Gorner Glacier in mountainous Switzerland is shown in this photo

CLIMATES OF THE PAST

by Charles Merrick Nevin

Climate plays a vital part in the drama of life. Every species of animal and plant develops best under certain limited conditions of sunshine, humidity, and temperature. It is reasonable to assume that living things in the past must have been influenced by climate in the same way.

We know something of the living things that dwelt in prehistoric times through the fossil record. There are many different kinds of fossils. They may be the remains of animals and plants, preserved through some accident of nature. They may be the imprints of once living things—plants or animals—in rock. The track of a worm clearly marked on sandstone or shale is a fossil; so is a skeleton of a mammoth, frozen with flesh intact; so are insects preserved in amber.

The fossil record of life goes back hundreds of millions of years. The fact that these records are more or less continuous for that period of time shows that climate must have been comparatively uniform. There have been numerous variations, indeed, as we shall see, but these have been within a relatively moderate range, compared with temperatures found elsewhere in the universe. Life has not been subjected to such high temperatures as exist in the sun and survived. But there is now reason to believe that certain forms of life are hardier than once believed. This is especially true of simpler forms, such as viruses and bacteria.

To account for the comparative uniformity of climate, we must assume that from a very early time, the earth had an atmosphere to shield living things from excessive amounts of heat and also to prevent heat from escaping freely into outer space. We must also assume that since the time when life appeared on the earth, the sun has been emitting radiation at about the same

National Coal Association

Fern-leaf fossil, formed by a plant that grew in the Carboniferous period. Ferns are signs of a warm, moist climate.

rate as today. Plant and animal life can exist on the earth only because of the warmth and light supplied by the sun. Any radical change in these respects would have catastrophic effects upon all living things.

Yet, as we have already noted, if climate has been uniform on the whole, there have been innumerable variations in its patterns. There have been periods when high temperatures prevailed and other periods when ice sheets covered the earth. We can prove that such conditions occurred by a study of rock formations, by the fossil records of animals and plants, and by other methods of analysis. The more pronounced departures from the normal pattern of climate are of particular interest. It was during these critical periods that some new forms of life died out, while others developed.

There are various ways of analyzing the nature and extent of climatic variations. For one thing, if we study present-day climates and their effects on living and nonliving things, we shall have a key to the analysis of the climates of the past. If we see that rocks and animal and plant life are affected in a certain way by this or that type of climate, we may assume that the same type of climate must have produced the same effects in past ages. This is the method of analogy, or comparison. It has to be used with care, because there are numerous exceptions, but it is decidedly helpful.

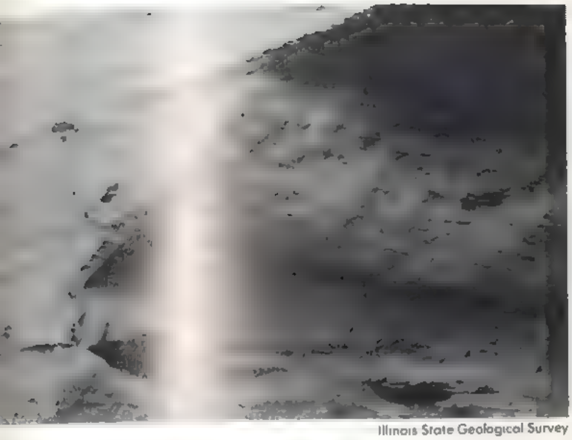
TYPES OF CLIMATES

We assume that certain types of climates existing today have had their counterparts in the past. Among the most significant of these climates are the (1) dry desert-type climate; (2) warm-moist climate; and (3) cold climate.

The dry desert-type climate. In a desert climate, wind is the chief agent that transports particles of sand and rock. We should expect to find the smaller grains of sand rounded, because of the action of the wind. Wind causes stones to rub constantly against each other. The fact that water is so scarce prevents the formation of a protecting film of water, which usually prevents the rounding of small particles in sediments laid down by the work of water. Another effect of dry climate is the frosting of sand grains, which results from the continual bumping together of the dry surfaces. This contrasts sharply with water-laid deposits, in which the surfaces of sand grains are usually bright and glistening. Still another effect of dry climate is the formation called cross-bedding, in which the different strata, or layers, show a curious wedgelike effect. This effect is characteristic of sand dunes. Cross-bedding develops over large areas in climates that are dry.

If thick deposits of salt gypsum are present in an area, it is likely that they were laid down in an arid climate. We may assume that the rate of evaporation exceeded the rate at which the deposits were precipitated.

Red soil deposits were formerly thought to be evidence of an arid or semiarid climate. This is true for many such deposits. However, very deep-red soils are now being produced by the weathering of certain rocks under a covering of tropical and subtropical vegetation. If the soil that results is transported to other regions, under certain conditions, a red-bed sediment will be formed. This particular sediment will have been due to conditions different from those of an arid environment.



Illinois State Geological Survey

This sandstone of the lower Pennsylvanian period shows cross-bedding, a geologic formation that is generally characteristic of dry, desert-type climate.

Warm, moist climate. The chemical weathering of rocks and minerals is at its maximum in a warm, moist climate. For example, under such conditions feldspar, a common mineral in the earth's crust, is changed to clay. In arid and frigid climates, the feldspar remains unaltered for a much longer period. This distinction serves as a valuable [illegible].

Vegetation flourishes in a warm, moist climate. As a result, the colors of sediments formed under such conditions are usually various shades of gray to black. Coal beds grade into deposits that give every indication of plenty of moisture. While growth is very rapid in a warm, moist climate, decay is also at its maximum. Hence, though growth is slower in a cold climate, the arrest of decay may cause coal deposits to accumulate more rapidly.

Fossilized forms of warmth-loving types of life give a significant clue to the existence of a warm climate. Among such organisms are butterflies, reptiles, earthworms, certain highly specialized mammals, sponges, snails, palm trees, cycads, and tree ferns. However, this particular rule does not apply in every case. A warmth-loving species may adapt to slowly changing climatic conditions. Ultimately it may come to flourish in an environment entirely different from the original one. For example, the elephants and rhinoceroses of today thrive particularly where it is warm. We know, however, that the mammoth (an elephant) and the woolly rhinoceros, both now extinct, flourished in a cold climate.

Thick beds of limestone formed by reef-building corals would seem to indicate a warm climate, because all present-day reef-building coral colonies live in warm seas. We must bear in mind, however, that all of the species of reef-building corals that made up the ancient limestones are now extinct. We cannot therefore be positive that they were as definitely restricted to warm seas as their living descendants.

Cold climate. The existence of glacial deposits are reliable indicators of a cold climate. In such deposits we find rock fragments existing in all sizes and shapes, which have not been sorted out. The boulders, too, are striated, or marked with grooves. This provides evidence of the glacial masses that deeply etched the rocks as they passed over the land. Likewise, finding fossilized forms of certain hardy vegetation, such as *Glossopteris*, indicates the existence of a climate such as we find today on the frozen tundras of Siberia.

This method of analogy must be applied with caution. Many of the findings we have mentioned are quite uncertain when considered separately. However, when we combine them with other types of evidence, we can obtain a fairly reliable picture of past climates.

HINTS OF THE PAST

Vegetation may serve as an indication of temperature changes. The advances and retreats of the ice sheets in various areas are reflected in changes in forest cover—changes denoted by the different types of pollen that have been preserved. Growth rings in ancient wood clearly mark former wet, dry, cold, and warm seasons.

To make an analysis of past climates, it is often very helpful to be able to date various organic remains more or less precisely. The method of radiocarbon dating has proved useful in this connection.

The laying down of sediment in the form of varves may also serve as a criterion. *Varves* are alternating layers of finer

and coarser sediment, formed on the beds of lakes in a seasonal climate. Fine, thin layers are laid down when the lake is frozen over. Coarser layers are laid down when spring streams carry in loose materials after the thaw. These alternating strata indicate seasons and perhaps longer cycles.

One method of past-climate analysis is based on the fact that the ice sheets of Greenland and the Antarctic consist of annual accumulations of snow. Scientists have developed a deep-drilling technique for bringing up ice cores from ice sheets. These cores show the annual snow accumulations and provide clues to the climates of the polar regions in past ages.

THE GEOLOGIC THERMOMETER

A fascinating new technique for studying past climates is the use of the so-called "geologic thermometer" developed by the American chemist Harold C. Urey, of the University of Chicago. It is based on the analysis of isotopes of oxygen. The isotopes of a chemical element represent the different forms in which the element may occur. All these forms have similar chemical properties, but they differ in atomic weight. For example, the three chief isotopes of oxygen are oxygen 16,17, and 18—also written O^{16}, O^{17}, and O^{18}, respectively.

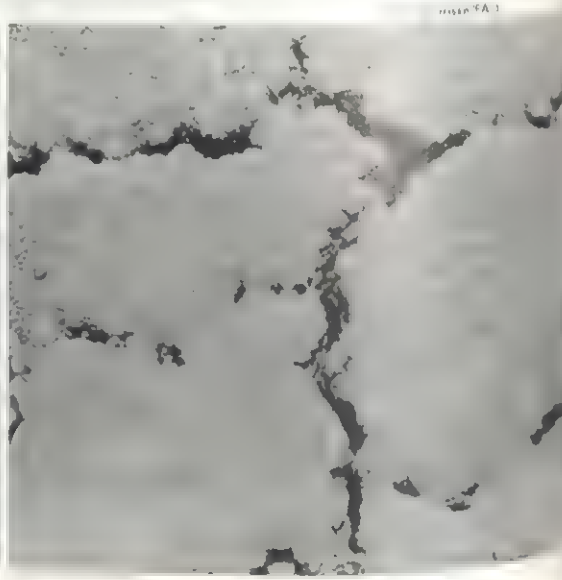
Urey made a study of the oxygen isotopes in water. The water molecule is made up of two hydrogen atoms and one oxygen atom. It has the chemical formula H_2O. Over 99.7 per cent of the oxygen atoms in the water molecules in a glass of water are O^{16}—oxygen with atomic weight 16. But certain water molecules are made up of hydrogen plus O^{17}, or hydrogen plus O^{18}.

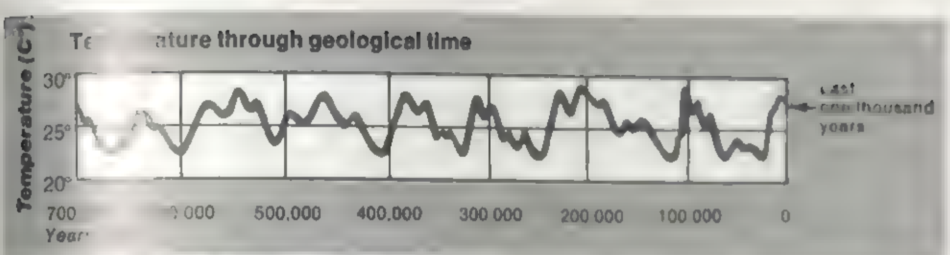
Urey noted that when a glassful of water evaporates, the three isotopes of oxygen—O^{16}, O^{17}, and O^{18}—do not all leave the liquid at the same time. The evaporation process will carry off a slightly higher proportion of the O^{16}. As a result the water will have a slightly greater concentration of the heavier isotopes—O^{17}, and O^{18} (particularly O^{18}). Urey noted that the water in the oceans had been subjected to the process of evaporation longer than fresh water. Hence it should have a high proportion of heavier isotopes of oxygen.

A Swiss scientist, Paul Niggli, observed that if this were true, it should give us valuable information about carbonate deposits, such as limestone. Carbonates all contain oxygen in their molecules. If they had been precipitated in salt water they would have a higher percentage of O^{17} and O^{18} atoms than if they had originated in fresh water.

Is the Sahara creeping southward? Severe drought in the early 1970s caused widespread starvation as the soil became parched and devoid of vegetation. Rains finally came, but the long-range prospects for the area remain a mystery.

United Nations/FAO





Parios Studio for Fortune Magazine

Fossil studies of the past 700,000 years indicate a series of major ice ages at about 100,000-year intervals, with periods of relative coolness and warmth alternating every 20,000 years. The modern era is rather warm.

Urey set out to analyze the difference in the isotope ratios in salt-water and fresh-water carbonates. He found that the comparative abundance of the oxygen isotopes other than O^{16} in the carbonate would increase with a decrease in the temperature of the water at the time the carbonate was deposited. He now realized that, as he put it, he had a "geologic thermometer" in his hands. By analyzing the temperatures at which carbonate fossils had been laid down, he would be able to find out something about the climate that prevailed during that period.

Urey and his associates, then at the University of Chicago, first analyzed "fossil temperatures" in 1950. They chose for this purpose the fossil of a belemnite, a creature resembling the modern squids. It lived about 140,000,000 or 150,000,000 years ago in the shallow sea that covered what is now Scotland. In cross section, the fossil showed rings like the growth rings of trees. Urey and his fellow-researchers shaved off the concentric layers one by one and analyzed the ratios of the oxygen isotopes in each one. The analysis showed seasonal changes of 15° to 20° Celsius during the growth of the animal's skeleton. It revealed that this particular belemnite had been born in the summer, lived almost four years, and then died in the spring.

The oxygen "geologic thermometer" is still in its infancy as a tool of science. It has been used, among other things, to analyze the variations in temperature during the latter part of the Age of Reptiles—the Upper Cretaceous period. The oxygen-isotope analysis of a large number of fossils from North America and Europe has shown that temperatures rose during the first part of the Upper Cretaceous and fell during the second part. The temperature kept dropping on into the Pleistocene, the so-called Ice Age.

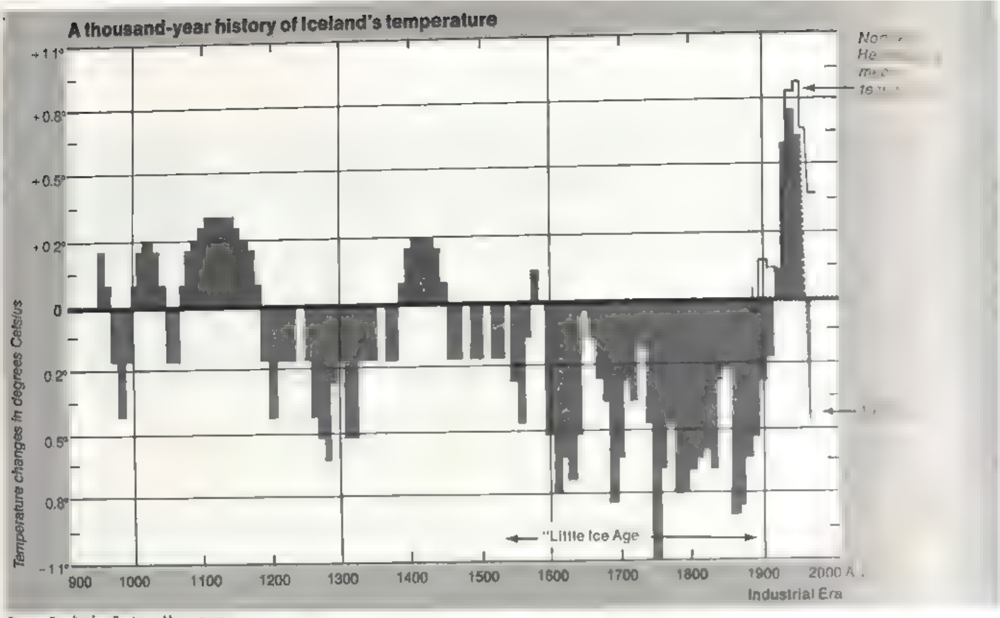
MANY WARM PERIODS

What have these methods of analysis revealed about the climates of the past? They show, for one thing, that there have been periods during which a warm climate extended from pole to pole. As a matter of fact, there have been such warm periods during the greater part of the earth's history. In many, glaciers were unknown.

Without exception, warm climates were associated with low-lying land. The continental areas were greatly reduced as a result of flooding by shallow seas. Broadly rounded hills, instead of the mountainous topography of today, were the rule. Immense oceans extended through wide channels from pole to pole. What is now New York had a subtropical climate. The climate of Greenland was warm to temperate.

Deserts have always existed. During the warm periods of the earth's history, however, they were greatly enlarged, extending from the equator far into the present temperate zones. As we have seen, different forms of life developed as the great climate changes came about. One of the most important occurred in this widespread desert environment—for the air-breathing vertebrates originated under these climatic conditions.

The earth's axis is inclined about 23.5 degrees to the plane of its orbit. As a result,



Parios Studio for Fortune Magazine

Iceland's temperature history, compiled from various sources, indicates that the world may be on the brink of a "Little Ice Age," similar to the one that prevailed from the sixteenth to the nineteenth century.

the tropics receive more heat than the middle latitudes, while the middle latitudes receive more than the poles. The inclination was probably the same in the past.

ICE AGES

Warm periods have alternated with cold. There have been eight major ice ages. They started in Pre-Cambrian times and were spaced about 250,000,000 years apart. Each occurred following a period of mountain-building and the raising of the land into high continents. It seems likely that the land-building activities were an important factor in the coming of the glacial period. For one thing, they brought about an increase in snowfall. Moist air would be forced up mountain slopes. Condensing as it struck the colder air at the mountain top, it would form clouds and the clouds would release their moisture in the form of snow. Then, too, as the continents increased in area, the oceans became smaller and were divided into separate seas. This reduced or even put an end to the flow of warm ocean currents to the polar seas. These seas then cooled very rapidly and became frozen over. Some geologists hold that any such accumulation of ice in the polar regions would have a tremendous chilling effect upon the rest of the world.

There were other possible factors. It is thought that volcanic dust may have been one of them. Volcanic activity was at its peak during the mountain-building periods that preceded the different ice ages. The dust resulting from eruptions consisted of very small particles, which might well have floated about in the air for years after an eruption. They may have been plentiful enough to deflect a considerable portion of the sun's rays, so that the earth would be deprived of its heat.

It has also been suggested that the decrease in the quantity of carbon dioxide in the air might have had something to do with bringing on the ice ages. Carbon dioxide serves as a blanket, absorbing some of the heat that is radiated away from the earth and thus preventing it from passing on into space. If, for some reason or other, there were a deficiency in the quantity of carbon dioxide, more heat than usual would be lost to outer space, and as a consequence the climate would become colder. Unfortunately, we have no way of knowing whether there was actually a deficiency in carbon dioxide in the atmosphere in the period preceding the ice ages.

WHY THE FLUCTUATIONS?

Some authorities think that the succes-

sion of cold and warm eras may have been due to fluctuations in the radiation of the sun. According to one theory, as the heat output of the sun decreased, it would cause temperatures on the earth to drop. There would be a slowing up of air circulation and less precipitation. The polar seas would freeze over, but no land icecaps would form because of the comparative lack of snowfall.

Suppose now that the heat output of the sun would begin to rise again, though not very much. Clouds would form; precipitation would increase, causing snow and ice to accumulate. Ice sheets would then form on the land. As solar radiation would increase still more in intensity, temperatures would rise notably on the earth. The ice sheet would melt and an interglacial period would result. Then the solar heat output would drop again, and the cycle would start anew.

Still other factors may have been at work. Variations in ocean circulation may have had some influence on long-term climatic changes. Changes in the earth's magnetic field may have influenced the climate, particularly since this field would have had an effect on the radiation from the sun. According to some authorities, the waxing and waning of glaciers has been affected by cyclic changes in energy emissions from the sun.

Each of the major ice ages consisted of several stages, during which the ice fields alternately advanced and retreated. The last great ice age, that of the Pleistocene, consisted of four distinct phases. M. Milankovitch held that these phases within ice ages were due to lower summer temperatures. He pointed out that ice sheets in the higher latitudes could melt only during the summer, and if the summer was very cool, they might not melt at all. That would mean that the following year's accumulation of snow would be added to all of the previous year's accumulation and would result in the spreading of the ice sheet.

Milankovitch held that the cooler summers would be due to various astronomical factors. The first would be a lengthening and narrowing of the ellipse formed by the earth as it revolves around the sun. Then the earth may also find itself at aphelion—the part of its orbit when it is farthest from the sun—in the summer. Finally, as it wobbled around its axis, the earth may also be in a position at a somewhat smaller angle to the plane of its orbit during the summer, instead of at the average inclination of 23.5°. However, as the orbit would become shorter and wider, as the earth would reach aphelion in seasons other than the summer, or as it would become more inclined to the plane of its orbit again, the summers would become shorter but hotter, and the ice sheets would recede. Milankovitch's theory is a plausible one. It has received considerable study and the support of some reputable authorities in the field.

Certain authorities attribute the waning and waxing of ice sheets in the Pleistocene to variations in snowfall. They argue that an ice sheet would press down on the land as it advanced, causing the land level to become lower. There would be less cloud formation and less snowfall. As the land would sink, it would let in the sea. The glaciers would melt and they would gradually break up. Relieved from the pressure of the glaciers, the land would rise again. There would be more cloud formation and more snowfall. Glaciers would begin to form again; and as ice sheets would encroach upon the land, they would press down heavily upon it and the cycle would be renewed.

AND NOW?

According to some authorities, the last of the four ice ages in the Pleistocene period came to an end only about 10,000 years ago. There are still traces of it in the icecaps of Greenland, the Antarctic, and other places. Weather records and the analysis of glacier formation indicate a distinct warming trend up to about 1940. This trend has been slowed up since that time, however, and may even have stopped. Some scientists also believe that man's pollution of the atmosphere affects its temperature in different ways and may bring about major changes in climate sooner than would otherwise be expected.

ENERGY

Left The British Petroleum Co. Ltd
Above Omaha Public Power District

Energy is needed to maintain our way of life. This energy is taken from several sources. Left: a drilling (production) platform taps an oil field in the North Sea. Above: loading nuclear fuel in a reactor. Many people feel that power derived from nuclear energy will solve our future energy problems.

THE ENERGY PICTURE

Throughout history, growing population and developing technology have demanded increasing consumption of energy. At first people met their energy needs with muscle power and then learned to use fire and animal power. Later, people harnessed the energy of the wind with sails and windmills, and flowing water was used to turn waterwheels. Today oil and natural gas provide more than two-thirds of the energy used in the United States and in the world.

Because of the enormous demand for these fuels, known resources are being exhausted and new ones have become difficult to find. Many people, however, remain unaware of the world's growing dependence on energy sources that may be exhausted in 25 to 50 years.

Coal is abundant enough to last 300 or 400 more years. It now provides about a third of the world's energy and about a fifth of the energy used in the United States. Although we will intensify our use of coal in the near future, it is time to make major changes in our patterns of energy consumption. We must find ways to make limited sources more energy-efficient. We must also turn to new and renewable sources of energy.

A largely untapped "source" of energy exists in the United States and elsewhere. It is energy conservation. It is safe, inexpensive, and readily available. If the United States made a serious commitment to conservation, it could cut energy use by one-quarter to one-third, according to experts. A combination of conservation, more efficient use of known resources, and development of new, renewable sources could avoid energy shortages and brighten the future.

A RISING DEMAND FOR ENERGY

The amount of fossil fuels (oil, natural gas, and coal) consumed in the United States has nearly doubled every 20 years since 1900. Between 1960 and 1980, the U.S. population increased by 25 percent. Total energy demand, however, rose by 80 percent—more than three times as much as the population. Similar patterns have occurred in other industrialized countries, particularly in those resource-rich nations that have experienced a rapid inflow of wealth. Thus, increase in energy demand is more directly correlated with economic growth than with population growth.

People have continually demanded additional goods and services that are energy-intensive, that is, have high energy requirements. This has been coupled with more energy use to increase the productivity of labor and capital. The productivity of heavy industry, agriculture, transportation, and services has been substantially increased by the use of energy-intensive tools, from jet aircraft to computers. For virtually all nations, the developing as well as the developed, the larger the per capita gross national product, the larger the per capita energy consumption. In the United States, energy and the gross national product have grown hand in hand at a rate of 3 to 3.5 percent for about 40 years.

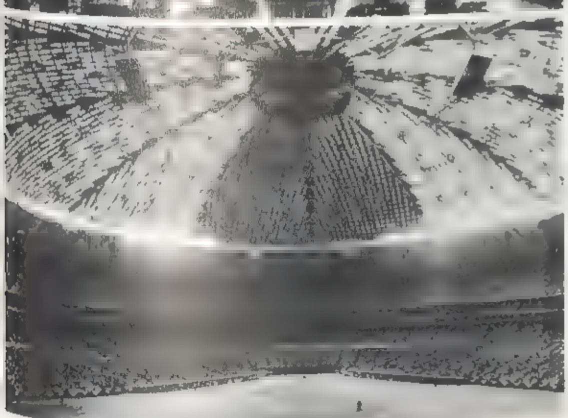
As nations shift from agricultural to industrial economies, vast increases in energy consumption occur for powering industry and for mechanizing and fertilizing farms. As their industries grow, nations develop energy-intensive transportation and communication systems to tie together the interdependent sectors of their economies.

A major trend in energy demand has been a dramatic increase in the use of electricity. In 1980 the United States used 380 times more electricity than it did in 1900. During the early 1980's, the demand continued to grow. However, conservation and new energy-efficient devices cut the annual growth in usage from 7 percent to 3 percent.

Usage will continue to increase because of rising living standards, but higher costs may act to reduce the rate of rise. Air conditioners, dishwashers, clothes dryers—all luxury items in the 1950's—are common-

U.S. Bureau of Reclamation

UPI



UPI

The high-voltage transmission lines crisscrossing the land, the night view of the New York skyline showing the World Trade Center, and the well-lit Houston Astrodome dramatically illustrate the demand for electricity in the United States.

place today. Suburban areas, with new homes using many of these appliances, are among the largest residential users of electricity.

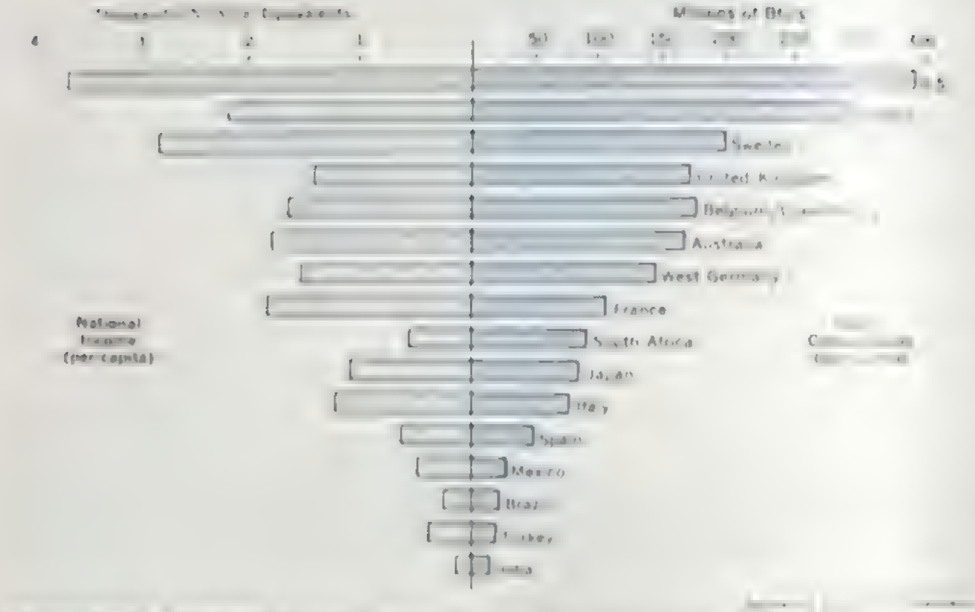
These trends have been mirrored in the commercial sector. Heated garages, escalators, and temperature-controlled sports stadiums and civic centers are examples of increased energy use by this sector.

Energy used for transportation has also increased steadily. For example, motor vehicles in the United States burned an estimated 115 billion gallons of gasoline in 1980 compared to about 91 billion gallons in 1970.

The increasing use of energy for transportation reflects not only growth in the distance traveled but also the change to more rapid modes of transportation that use more energy. There is now about one automobile for every two people in the United States. The two-car family is a way of life, and three-car families are no longer uncommon. Freight transportation has become more energy-intensive. The volume of air and truck transportation has grown dramatically, while more energy-efficient rail and waterborne transportation has increased only slightly.

Although its energy demands are less visible to the public, the production of manufactured goods and agricultural products increasingly consumes more and more energy. Indeed, industry is the largest user of energy. It provides the power for the extraction of minerals, refining of resources, and the mechanical work of mass production. Manufacturing output in the United States more than doubled between 1960 and 1978. In the early 1980's, manufacturing suffered setbacks due first to inflation and then to recession. Rates of productivity fell, as did the utilization of factory capacity, while unemployment rose. In contrast, energy-intensive devices such as robots, computers, and automated systems began

Per Capita Income and Energy Consumption



[illegible] Btu's.

to replace human workers, in some measure because labor costs rose more rapidly than energy and equipment costs.

Continuing urbanization, higher-speed transportation for both people and merchandise, and the increased use of labor-saving devices have been stimulated by relatively low energy prices. Now, however, the United States and many other industrialized nations face energy supply problems, dependence on imported oil, and the [illegible] security problems [illegible] and damage to the environment caused by increased fuel extraction and use. These problems are forcing careful consideration of ways to slow the accelerating use of energy. Such consideration [illegible] energy supply systems, sources, and uses.

Energy Systems

Heating a home, lighting a factory, or flying a [illegible] requires complex interrelated energy systems. An energy system consists of all of the components necessary to bring a basic resource from its natural state to the place and form in which it is used. For most energy systems, this involves extraction of fuel, processing, perhaps conversion into a more useful form, transportation between the various operations, delivery or transmission to the ultimate user, and use.

Producing electricity from coal, for example, requires extraction of the coal from underground or surface mines; then processing for removal of impurities; and transportation by railroad, truck, barge, or pipeline to a power plant. At the power plant, the fuel is burned and its heat used to produce steam to drive a turbine. The rotating turbine is connected to a generator that converts the energy of rotation into electricity. Finally, electricity is transmitted by power lines to homes, offices, and industrial plants, where it has many uses, including lighting, heating, and powering machinery.

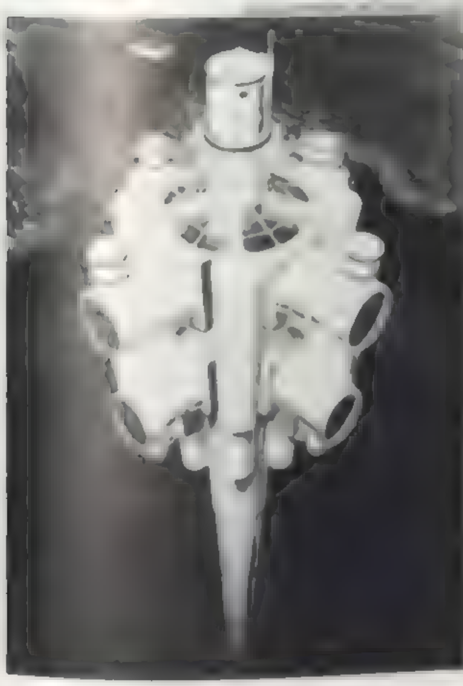
C[illegible]oleum, and natural gas provide [illegible]n 90 percent of the energy used i[illegible]orld and in the United States. Expe[illegible]ast that these fossil fuels will still [illegible]re than 75 percent of world energ[illegible] by the year 2000. Hydropowe[illegible]power) provided about 5 percent [illegible]lear power about 4 percent of U.S. [illegible]eeds in 1983. (For the world, the [illegible]ere 2 percent and 1 percent, respe[illegible] By the year 2000, hydropowe[illegible]ted to decline to about 3 percent [illegible]uclear power to increase to about [illegible]ent of U.S. needs.

[illegible] most abundant fuel in the world. [illegible] provides about 30 percent of the w[illegible]nergy and about 22 percent of that u[illegible]he United States. As supplies of oil [illegible]ral gas decrease, coal's share of the [illegible]nergy market will increase. If the present growth in energy consumption continues, by the year 2000 coal's share of the U.S. energy market may rise to as much as 35 percent.

Environmental problems, particularly air pollution, will restrict the use of coal. Coal-burning plants release sulfur dioxide, which combines with moisture in the air to produce acid rain. This destroys forests and lakes and damages buildings. For the present, environmental considerations limit the use of high-sulfur coal. In the future, technology to remove sulfur compounds after combustion, or to convert coal to a cleaner-burning liquid or gas, is expected to extend the use of coal while decreasing pollution.

Concern also exists about the destruction of coal lands by surface, or strip, mining, and about dangers to the safety and health of miners. Introduction of new laws to protect miners and the land can reduce

Researc[illegible] the technology to use the sun's energy [illegible] a subm[illegible]ting platform designed to convert the sun's energy [illegible] [illegible] right: 1,800 giant movable mirrors in California's Mojave Desert reflect [illegible]nto a central tower to produce steam to generate electricity.

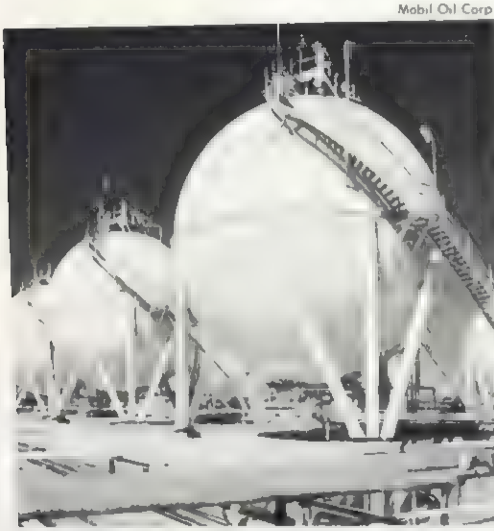


or eliminate many of the problems. Land reclamation laws already are requiring mining companies to put back the soil they remove and replant vegetation that was destroyed. However, effective emission-control programs, mine-safety measures, and land reclamation require time and money. In the recession of the early 1980's, the need for jobs as well as for the cheapest possible energy sources slowed progress in these areas. Future levels of coal production may hinge on the relative strengths of economic versus environmental factors.

Oil is now the most intensely used energy resource in the United States, meeting about 46 percent of the countr needs. It is expected to remain the pri y energy source until the end of the ce . Unlike coal, however, U.S. demand l cannot be met solely from domesti duction. The country imported 28 per f the petroleum it used in 1982. Pr U.S. reserves of oil totaled about 30 barrels. Availability of this domestic e supply depends on factors such as m t prices, the economics of oil recover competition from alternative energy ces. For example, it may be less costl port oil than to tap domestic reserves

The United States, Japan the nations of Europe have been tr reduce their dependence on importe particularly from the Middle East. A bargo by Arab nations in the early 19 d to oil shortages and dramaticall creased prices. This adversely affected national economy and posed a potent k to the security of the United States very of new sources in Alaska and here, as well as conservation efforts by high prices, enabled the United Sta reduce

Mobil Oil Corp



UN

Natural gas, hydropower, and nu wer now provide about 25 per cent of th s energy needs. Top left: natural gas storag Bottom left: a new hydroelectric power pla hodesia Bottom right: cooling towers and r and turbine buildings of a nuclear plant

Atomic Energy Commiss in Edison Co

imports by more than half between 1979 and 198[illegible].

Natural gas meets about one-quarter of U.S. energy needs. Proven reserves stood at about 6 trillion cubic meters in 1982. This represented only about three-quarters of the figure of some 20 years earlier because gas consumption has exceeded discovery of new sources. Experts predict that natural gas will satisfy only about a tenth of U.S. energy needs by the year 2000.

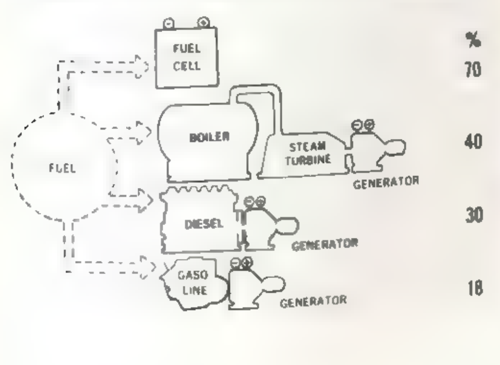
The decline of domestic reserves is a concern because natural gas is the cleanest fossil fuel. Importation raises the same economic and security problems as it does with oil. The availability of the proven reserves is governed, as it is with oil, by a complex of economic, technical, and environmental factors. Pinpointing the reserves and extracting the gas involves drilling deeper—and the deeper the holes, the greater the costs. For this reason, economic incentives, such as higher national gas prices and tax allowances for exploration expenses, can stimulate development of natural gas reserves.

In the early 1980's, about 15 percent of the electricity generated in the United States came from burning natural gas. This compares with more than 50 percent from coal, 7 percent from oil, and 11 percent from hydropower. Nuclear energy, used almost exclusively for power generation, accounted for 11 percent.

Energy power systems must be evaluated in many ways. Although fuel cells are theoretically highly efficient—about 70 per cent—and environmentally clean, they are costly.

Pratt and Whitney

COMPETITIVE POWER SYSTEM EFFICIENCY



Hydropower also goes almost solely for generation of electricity. Although water power is historically an important energy source, it meets only about 4 percent of total U.S. needs. Its growth potential is limited because few economical and environmentally suitable sites exist for new hydroelectric facilities.

Alternate energy sources now in the research and development stages may eventually supply much of the energy required by the United States and the rest of the world. The technical and economic feasibility of these alternatives has yet to be demonstrated, however. Fuel cells, for example, operate at an efficiency of 70 percent for generating electricity, as opposed to 40 percent or less for fossil fuels. Gaseous or liquid fuels, such as hydrogen and oxygen, react chemically in the cells to generate electricity directly, without boilers or turbine-powered generators. Little pollution or waste results, making fuel cells environmentally desirable. The cost of fuel cells, however, is not low enough to com-

Heating plant. Coal is delivered to large complexes such as this one to heat water. In the future, solar collectors may be used instead of coal.

Rotkin - PFI


School of Electrical Engineering, University of Oklahoma

Many programs are underway to examine wind power as an energy source. This model, built by researchers at the University of Oklahoma, is very efficient.

pete with fossil fuels or nuclear energy. Consumers would not want to pay the price for electricity generated by fuel cells.

Implementation of such new technologies can quickly change both the rate of use of particular energy resources and incentives to develop other alternate sources. Consequently, any long-term estimates of total energy use and energy-system mix are subject to uncertainty and error. In the future, the price of energy will be determined by technology, resource availability, the requirements of environmental protection, and various political factors.

ENERGY AND THE ENVIRONMENT

Converting fossil and nuclear fuels into energy leads to air pollution, water pollution, creation of solid wastes, land disruption, and aesthetic degradation.

Air pollution. Energy systems are the largest source of pollutants emitted into the air. Automobiles and other forms of transportation, and stationary sources, including power plants and residential and commercial heating units, release millions of tons of gas and noxious particles into the air each year. These pollutants cause discomfort and endanger health. Particles can irritate the lungs and worsen respiratory diseases. They also may cause or contribute to emphysema and cancer. Rates of illness and death increase during prolonged periods of heavy pollution.

Air pollutants also harm plants, such as crops and trees. Most construction materials, including steel and concrete, wear out sooner in polluted air than in clean air. Particles in the air scatter sunlight and may cause a drop in local temperatures. Gases such as carbon dioxide prevent heat from escaping into the atmosphere and may produce a long-term rise in average temperatures.

Water pollution. Oil is discharged into water from accidents to drilling rigs, pipelines, storage tanks, or tankers. Massive spills that occur near shorelines have damaged recreation areas; seashore life; and the spawning grounds of fish, shrimp, and other aquatic animals.

Although oil tanker accidents often result in large spills, the cumulative amount of petroleum discharged intentionally from oil drilling, transportation, and tank-cleaning operations exceeds that spilled unintentionally. Such wastes result from incomplete separation of crude oil from brines brought up by drilling and disposal of brines in inland waterways and at sea. Discharge of brines—several barrels of which are produced for every barrel of oil—can contaminate freshwater supplies and adversely affect marine ecosystems. Furthermore, the cleaning of oil tanker holds and ship bilges is a significant source of oily wastes discharged into the oceans.

Coal extraction also is a source of water pollution. The Department of the Interior estimates that tens of thousands of kilometers of streams and tens of thousands of hectares of lakes in the United States have been polluted by acid mine drainage and sediment deposition from coal mining and processing.

Water that is used for cooling in industrial plants is much warmer than the bodies of water into which it runs. The major source of such thermal discharges is from power plants. The effects of thermal discharges are not fully understood, but they alter and may damage the natural balance of aquatic life. They may degrade lakes, bays, estuaries, and rivers. The effects vary with the temperature, rate, and constancy of discharge; the size of the receiving body of water; the climate; and the uses to which the water is put.

Land use. Surface, or strip, mining, in which huge power shovels remove rock, vegetation, and soil covering coal and other minerals, has affected more than 800,000 hectares in the United States. Stripping the land destroys its value for recreation, wildlife habitation, and other uses. There has been substantial regulatory action to prevent and remedy this. About one-third of stripped land has been reclaimed in some fashion.

Other energy activities occupy large areas of land or destroy its scenic value. Overhead transmission lines and rights-of-way for them use millions of hectares.

Solid wastes. Mining wastes associated with energy systems account for a substantial portion of the 4 billion metric tons of waste produced in the United States each year. Further, the combustion and processing of fuels, particularly coal, add significantly to the total contributed by energy systems.

Nuclear power plants produce more thermal pollution than fossil-fuel plants, but less air pollution when they operate properly. Nuclear plants have created a major environmental problem that involves disposal of high-level radioactive wastes. Spent fuel contains radioactive materials that remain dangerous for thousands of years. In December 1982, the United States passed the Nuclear Waste Policy Act to deal with the problem of wastes that had accumulated for almost 40 years and that continue to accumulate. The act calls for permanent storage in deep underground mines or repositories. The first repository site is to be chosen in 1987 (see *Waste Disposal* in the article on Nuclear Energy). After storage, the wastes must be carefully monitored to detect any leakage. They also must be guarded to prevent digging up for unauthorized uses.

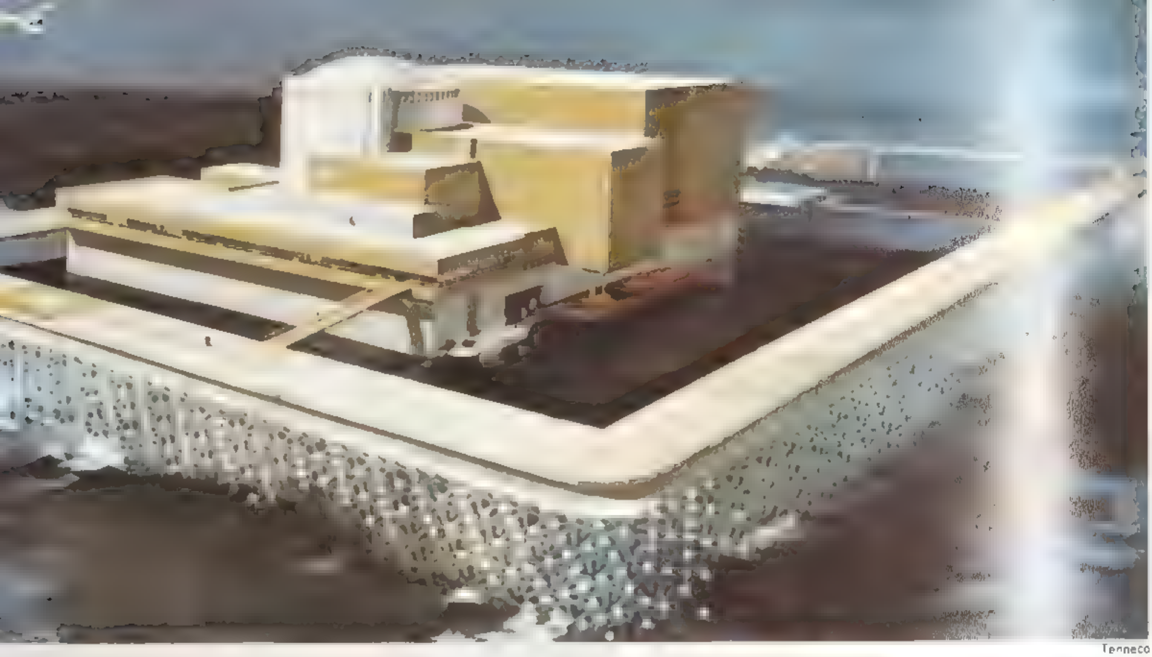
Perret—Fotogram

There is a very large amount of heat produced in a geyser field. Many scientists have suggested using this geothermal energy to run turbines to produce power

THE FUTURE

We are using more and more energy-intensive devices in every sector of the U.S. economy, and many energy-intensive technological developments have become integral to our life-styles. Because pricing has not generally included the costs of environmental protection, the costs of this energy have been unrealistically low. These costs will increase as more control devices become mandatory and oil and gas get scarcer.

Utility rates already have risen sharply in many areas. Earl T. Hayes, former chief scientist of the U.S. Bureau of Mines, summed up the situation: "We have sufficient energy resources to supply our basic needs for many decades, but . . . we will



Tenneco

A possible solution to the energy crisis: nuclear power plants on floating offshore platforms. The plants would break down seawater into oxygen and hydrogen. Hydrogen would then be burned, releasing energy.

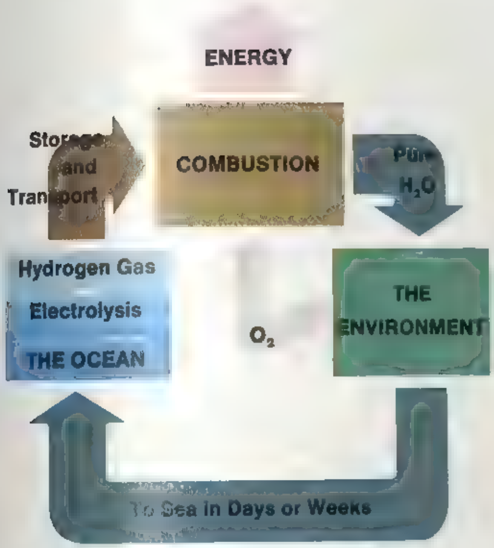
never again have as much oil or gas as we have today, nor will it be as cheap. Nuclear energy has been a major disappointment. Solar energy will be slow in developing and, contrary to popular opinion, expensive. Coal is the only salvation for the next few decades."

Coal, however, is a major source of air and water pollution. This will probably slow development of coal resources, and antipollution measures will add to the cost of coal-produced energy. There are programs for converting coal to liquid and gaseous fuels to replace petroleum and natural gas (see the article on Alternate Energy Sources). But these so-called synthetic fuels are not pollution-free, and they are much more expensive to produce than coal.

In 1977 the federal government presented a national energy plan with three overall objectives: (1) to reduce U.S. dependence on imported oil, (2) to weather the decline of world oil and gas supplies, and (3) to develop renewable and essentially inexhaustible sources of energy. Much progress has been made toward the first objective. As a percentage of the total oil used in the United States, imports were reduced by more than half between 1978 and 1983.

Conservation is an important element of the second objective, and encouraging signs also exist in this area. People in factories, offices, and homes have been installing more insulation, lowering their thermostats in winter, and raising them in summer. Many new offices and homes are being designed with conservation as a criterion. During the oil shortages of the 1970's, people drove less and sales of small cars increased. As the price of gasoline dropped in the early 1980's, however, people began driving more and buying larger cars. Conservation must be a continual effort, and a great deal more can be done to reduce energy consumption.

Availability of lower-cost oil has blunted the effort to develop renewable and technologically innovative resources. Nevertheless, many promising technologies are on the horizon. They include solar, geothermal, and fusion energy (see individual articles on these subjects). Limited uranium resources cloud the future of nuclear energy. Breeder reactors, which make more fuel than they consume, provide a silver lining, but the problem of stockpiles of material that can be used for making nuclear weapons has tarnished this alternative in the United States. This is not the case in



The hydrogen fuel cycle is efficient. Hydrogen from the sea is burned, giving off water vapor, which is quickly returned to the sea.

other countries (see *Breeder Reactors* in the article on Nuclear Energy).

All alternatives require much time and money before they can progress from research projects to practical commercial systems. Meanwhile, people will have to adjust to the involuntary conservation that will be brought on by decreased supplies and higher prices. A change in awareness and attitudes helps in making these adjustments. As Hayes puts it: "The country still does not understand the problem. The layman wants to believe in inexhaustible cheap energy and in this has been supported by many unsubstantiated claims. The time has come to realize that no miracle is imminent and we must make do with what we have."

A nuclear reactor plant in France. The use of nuclear energy to produce electricity is expected to increase dramatically—and so will the problems of disposing of radioactive wastes.

Brigaud – E D F

Alyesko Pipeline Co

The "Christmas Tree" an array of valves and gauges caps a well in Alaska's North Slope field.

PETROLEUM

Petroleum has often been called liquid gold, because of its value in our modern civilization. It is, of course, far more useful than gold. Our agriculture, industry, transportation, and communication systems depend upon petroleum in hundreds of ways, and the possession or lack of it can vitally affect all the activities of a nation.

Although the first commercial oil well was sunk as recently as 1859 near Titusville, Pennsylvania, man has been making use of petroleum for various purposes as far back as we have any human records. The dark, sticky crude oil has long seeped and oozed from cracks in the earth in many parts of the world. The substance called pitch in the Bible was probably crude petroleum.

EARLY USES

Archaeologists have found that petroleum was used by the Persians nearly six thousand years ago as mortar in buildings and as a kind of glue for other uses. The Greek traveler and historian Herodotus, who lived in the fifth century B.C., had quite a bit to say about the use of petroleum in the Persian Empire. He described the process of drawing the oil out of the shallow surface wells, commenting that it was "dark and evil-smelling."

Throughout that part of the world which we now call the Middle East there were a great many seepages. These were sometimes ignited by chance and became the "eternal fires" of the Persian fire-worshipers. The ancient Persians used petroleum in warfare. They shot arrows tipped with burning pitch into the ranks of their enemies.

The Venetian traveler Marco Polo visited the oil fields of Baku on the Caspian Sea toward the end of the thirteenth century on his way to the court of Kublai Khan, the great Mongol emperor of China. He told of "a fountain from which oil springs in great abundance, inasmuch as a hundred

Exxon

Derricks on the drill sites at Prudhoe Bay, an oil-and-gas field in northern Alaska.

Exxon

shiploads might be taken from it at one time," and added that "this oil is not good to use with food, but it is good to burn." He also mentioned that the people used the oil as an ointment to cure camels of the mange. Baku, which is now a part of the Soviet Union, is one of the world's famous producing fields.

The early explorers of North America found oil oozing out of the ground or floating on the surface of water in many places. The Indians used to rub their bodies with this mineral oil, believing that it toned up their muscles and made them active and quick. The colonists who settled in the eastern part of the continent also began to use the oil to a certain extent. Sometimes they would recover it by soaking blankets in the seepages and then squeezing the oil out of them into vessels. They would also skim floating patches of oil from the surface of water. Very little was obtained by this means. It was sold at a high price for medicinal purposes. Peddlers offered it under such names as Seneca oil or Indian oil, and it was supposed to be a wonderful cure-all. It was rubbed on externally to cure rheumatism and also taken internally as a medicine.

FIRST WELLS

In western Virginia, about the year 1806, men boring wells to get brine (salt water) kept finding oil mixed with the brine. They were greatly provoked because the oil interfered with the usefulness of the wells. Naturally, at that time no one could have any idea of the future importance of petroleum in commerce and industry.

In the year 1846, oil for burning was obtained from coal by a Dr. Abraham Gesner of Nova Scotia. Dr. Gesner called this oil *kerosene*, from the Greek word *kēras*, meaning "wax." A company was formed to manufacture it, and it was so successful that other coal-oil companies were established. This brought about a new interest in petroleum. In a series of experiments in

In the foreground, aboard Exxon's tanker, the *Esso Scotia*, is the ship's gear for linkup at a special port facility to unload its oil.

1855 at Oil Creek, Pennsylvania, Professor Benjamin Silliman of Yale College showed that petroleum was quite as good for burning as oil from coal.

Because of the growing demand for petroleum, people who owned oil-ruined salt wells began to market this oil in order to get some return from their property. There were many such wells around Titusville, Pennsylvania. A group of businessmen decided to drill there for oil, making use of the derricks and other equipment employed in drilling salt wells. The group engaged a retired railroad conductor, Edwin L. Drake, to take charge of the enterprise. Drake got hold of an expert driller of salt wells, William A. Smith, and this man, with his two sons, brought in the first drilled well in the summer of 1859. This was the birth of the oil industry. Vast quantities of petroleum have been made available to man by oil companies since then.

COMPOSITION AND ORIGIN

Petroleum is an oily, inflammable liquid made up mostly of hydrocarbons—compounds containing only hydrogen and carbon. The hydrocarbon content of petroleum ranges from 50 per cent to 98 per cent. The rest is made up chiefly of organic compounds containing oxygen, nitrogen, or sulfur.

How was petroleum formed? According to a widely held theory, the remains of countless small marine animals and plants dropped to the ocean bottom and were covered over by mud. Many layers of mud and plant and animal remains accumulated in the course of time. These sediments were subjected to great pressure and heat, and were often squeezed and distorted as the earth's crust moved. Gradually they were converted into layers of sedimentary rock.

The plant and animal remains contained within them were transformed into petroleum and natural gas. The details of this transformation are not quite clear. Some scientists point out that the cells of living marine animals and plants contain hydrocarbons. They maintain that a part of the hydrocarbon content of the cells was preserved after the plants and animal remains decayed, and that in time petroleum was formed from these hydrocarbons. Other authorities believe that bacteria removed oxygen, sulfur, and nitrogen from buried organic matter and converted it into a petroleumlike substance containing hydrocarbons. Perhaps both processes were at work.

Gulf Oil Corporation

A group of tugboats escorts a supertanker to its mooring place. These tankers can transport large quantities of crude oil at relatively low costs, but their docking presents a problem.

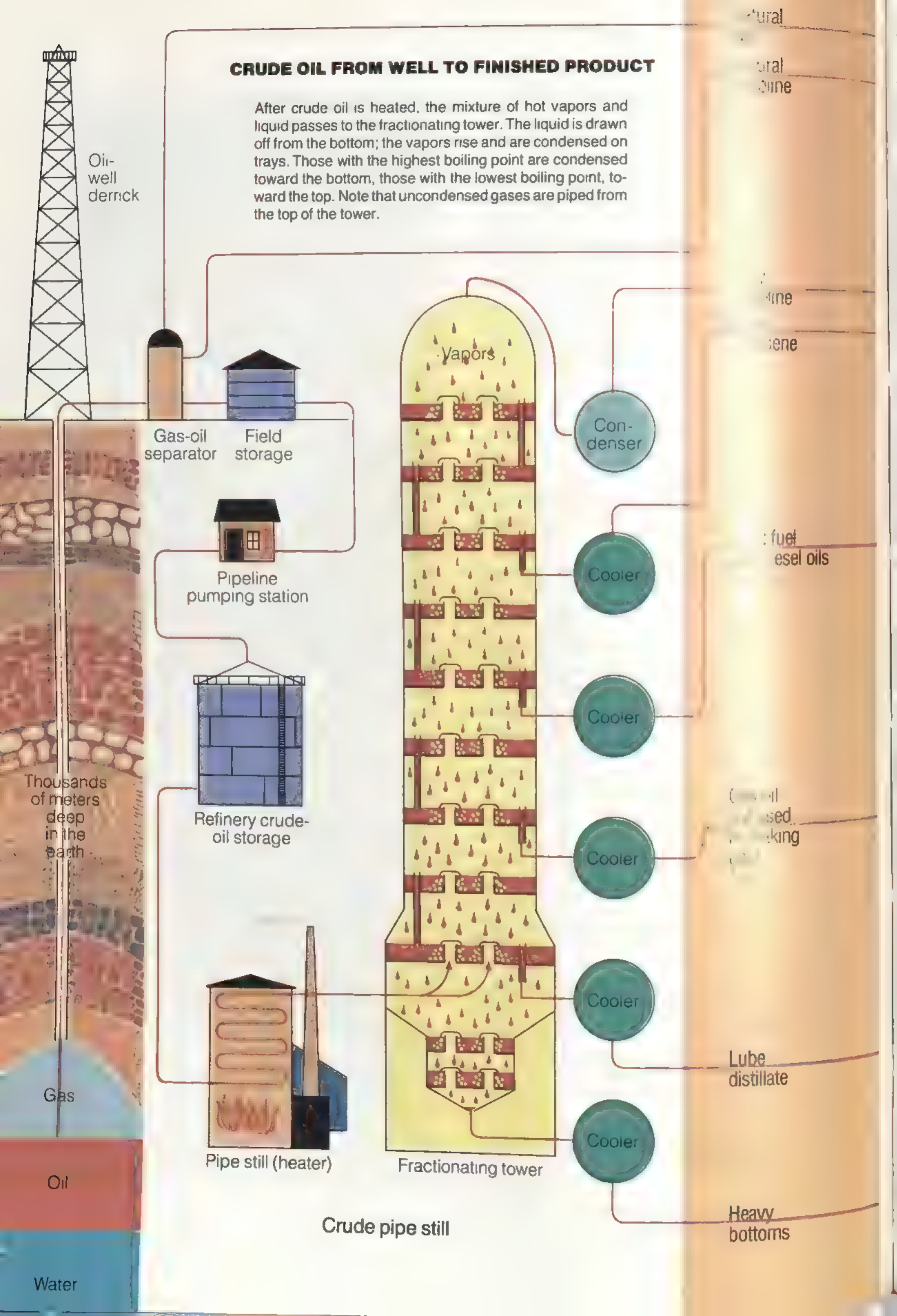
The oceans have receded from many of the areas in which these transformations took place. In other areas, the petroleum-containing rock formations still lie under the waters of the sea.

WHERE MOST IS FOUND

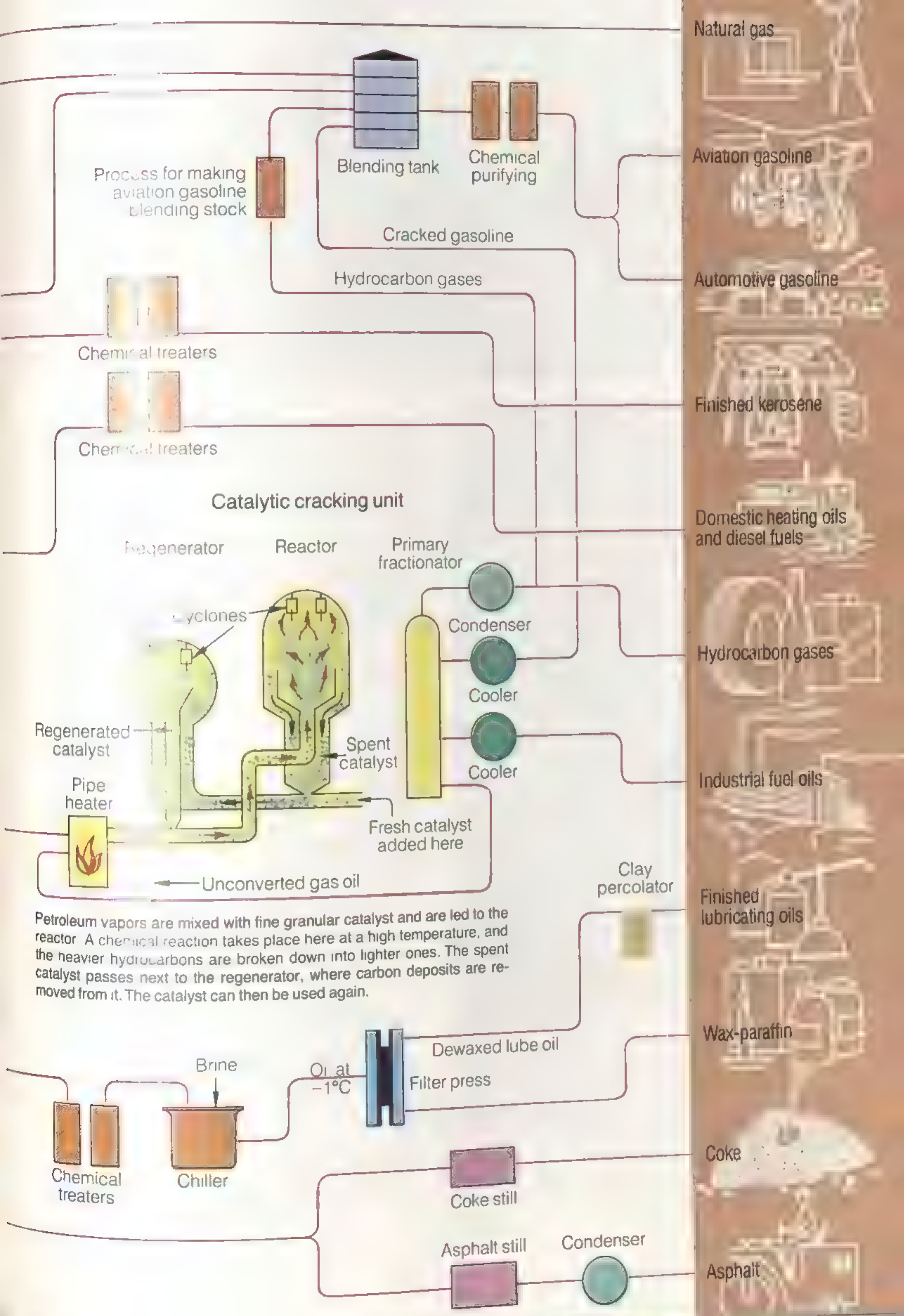
Petroleum deposits may occur on the surface of the earth in the form of seepages or springs, derived from the rocks below.

CRUDE OIL FROM WELL TO FINISHED PRODUCT

After crude oil is heated, the mixture of hot vapors and liquid passes to the fractionating tower. The liquid is drawn off from the bottom; the vapors rise and are condensed on trays. Those with the highest boiling point are condensed toward the bottom, those with the lowest boiling point, toward the top. Note that uncondensed gases are piped from the top of the tower.



Crude pipe still



Petroleum vapors are mixed with fine granular catalyst and are led to the reactor. A chemical reaction takes place here at a high temperature, and the heavier hydrocarbons are broken down into lighter ones. The spent catalyst passes next to the regenerator, where carbon deposits are removed from it. The catalyst can then be used again.

Ho. es-Lebel

ARAMCO

Above: offshore oil reserves will be exploited more and more to meet future needs for energy. Special derricks, drilling rigs, and drilling ships will be used. Left: an oil refinery in Saudi Arabia, one of the largest oil producers in the world. Opposite page: a refinery in Mexico. The oil refining capacities in Mexico cover the country's needs for motor fuel.

Sometimes the surface deposits may be changed to asphalt through the escape of volatile elements or through chemical changes. The asphalt may be a thick liquid, sticky enough to trap animals, or it may be so hard that one can walk on it. Surface deposits may also take other forms.

Most petroleum deposits are found underground. They are contained, together with brine and gas, in porous, spongelike layers of rock, such as limestone and sandstone, and they are obtained by drilling. The oil that is reached by successful drilling is found in oil *traps* of various kinds. A trap closes a petroleum reservoir so that the oil and gas it contains cannot escape. The gas, oil, and water within the trap form three distinct layers, the gas being uppermost and the water bottommost. The upper boundary of a reservoir trap is known as *cap rock*. It is always impermeable. The lower boundary is the oil-water contact.

Most of the world's oil deposits occur in *anticlines*—upward folds of stratified rock, forming arches. A deposit may also be trapped by a *fault*—a fracture in the earth's crust. As a result of the fault, a porous layer has been hemmed in by a nonporous one. Or a porous layer may occur between nonporous layers. The formations called *salt domes* are often associated with petroleum deposits. They consist of intrusive bodies of rock salt which have forced their way through the overlying sedimentary rock, forming a dome.

We have pointed out that gas and wa-

ter are trapped with the oil. Sometimes it is the pressure of the escaping gas that forces the oil to the surface of the earth when the drill reaches the trap. Wells of this sort are called gas-driven. In the so-called water-driven wells, it is the water in the trap that forces the oil upward. Until oil engineers devised means of controlling the upward pressure, a great deal of valuable oil was wasted when a successful drilling operation brought in a "gusher."

OTHER DEPOSITS

Oil is also found in oil shale, a compact sedimentary rock from which the petroleum is obtained by the process called *destructive distillation*. The shale is first crushed. Then it is heated in a furnace into which air is not admitted. The temperature is kept high enough so that chemical decomposition can take place. The principal products are oil, gases, and water solutions of organic acids and other substances. Scotland and Australia produce some oil in this way.

Major shale deposits occur in Brazil and in the United States in Colorado, Wyoming, and Utah. It is estimated that these deposits could yield more than 2 billion barrels of oil. One difficulty that arises in working with oil shale is that large amounts of shale must be handled to obtain the oil. This is extremely costly and potentially harmful to the environment. Economical mining methods are still being investigated, but commercial facilities are not operational in the United States. The major U.S. pilot project, in western Colorado, was canceled in 1982.

Another form of oil deposit that cannot be tapped by ordinary methods is tar sand. The two largest known tar sand deposits in the world are the tar belt of eastern Venezuela and the Athabasca tar sands in the northern part of Canada's Alberta Province. The Athabascan region contains one of the largest known deposits of petroleum in the world. It is estimated that perhaps 700 billion barrels of oil could be recovered from the region. Tar sands are mined and then washed in hot water to remove the tar from the sand. The tar is then heated and "cracked," or broken down, into simpler molecules, which are upgraded and blended to produce synthetic oil. Commercial operation began near Fort McMurray, Alberta, but a world slump in oil prices in the 1980's discouraged expansion.

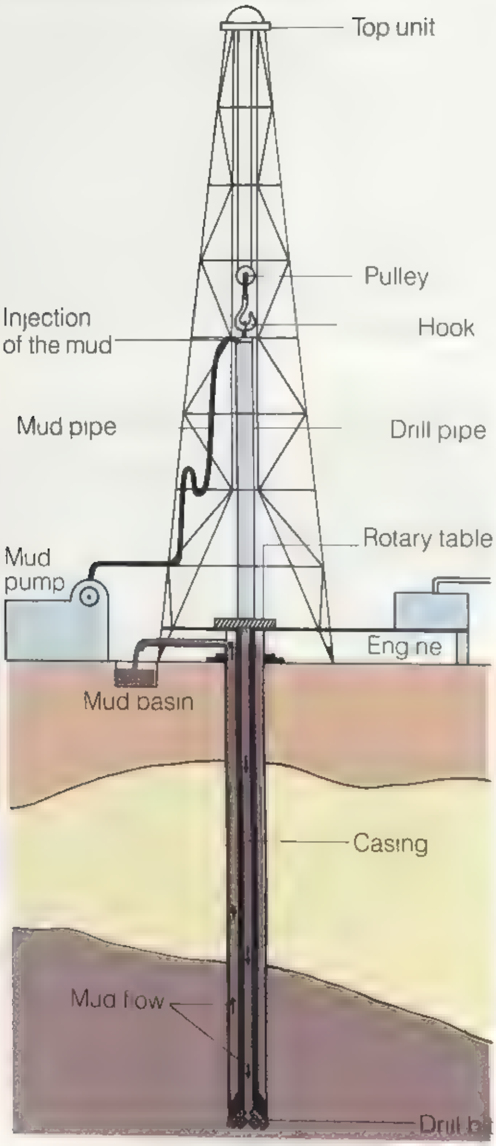
LOCATING THE RESOURCE

The amount of oil obtained from oil shale or tar sands by the distillation process represents as yet but a small fraction of the world supply. As we have pointed out, most of our oil is made available by drilling in order to get at the oil imprisoned in various traps. This is an expensive procedure under any circumstances. The ultimate cost depends to a great extent upon the depth to which the well has to be drilled and the hardness and thickness of the rock through which the drill must go. The expense of bringing in one well may come to several million dollars. In view of the high cost, drillers want to be reasonably sure that there is oil under the exact spot where they erect their rigging. The geological prospector helps obtain this information.

The different regions of the earth have been studied intensively to determine which areas are likely to be petroliferous, or petroleum-bearing. Surveys of various kinds have been made, and aerial photography has been used. In order to locate oil, such devices as gravity meters, magnetometers, and seismographs have been employed.

The earth's force of gravity is greater for a heavy rock near the surface than it is

DRILLING AN OIL WELL



Drilling an oil well. In rotary drilling, a hole is bored into the earth by a steel drill bit. The bit is cooled by a flow of mud around it.

for one farther down or for a light rock. By using the gravity meter, the variations in gravity can be measured and the deformations of underground rock layers can be studied. In this way traps containing oil may be detected. The different kinds of rocks under the surface of the earth affect the earth's magnetic field, and the variations thus caused can be measured by the magnetometer. The seismograph, as we know, is used primarily for measuring and locating earthquakes, but it is also helpful in locating oil domes or pockets under the earth. The geophysicist simply creates a miniature earthquake by setting off a heavy charge of dynamite. Then by means of a portable seismograph he can determine the speed at which the echo from each kind of rock comes back. From these echoes the geophysicist can chart the rocks underground and can determine which areas are worth drilling.

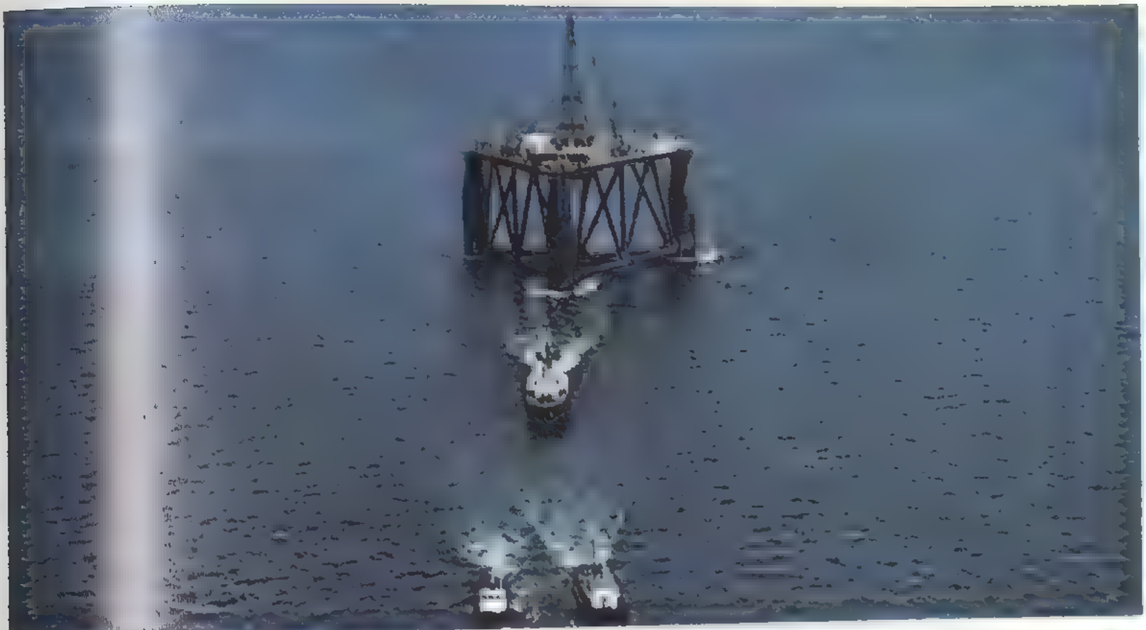
To check even more closely on the nature of the rocks and the presence of oil, gas, and water, further tests are made while the well is being drilled. This is done by means of an electric device, which is lowered into the well. It sends an electric current through the surrounding strata, recording differences in resistance to the current. In spite of these and other scientific tools, not every drilling operation that is undertaken is successful.

DRILLING METHODS

The oldest drilling method in use is called cable-tool drilling. In cable-tool drilling, the hole for the well is punched by a heavy, sharp bit, or cutting tool, attached to the end of a cable. The bit is raised and dropped over and over again until the necessary depth has been reached. This method was widely used till about 1920. It could not serve to drill really deep wells; hence it has been largely replaced by a method called rotary drilling.

In sinking a modern oil well, the first step is to build a platform to hold machinery and pipe connections. Then a steel framework tower is built. This is the derrick, which is used for raising and lowering drilling equipment into the well. It may be as tall as a seventeen-story building.

In rotary drilling, a hole is bored into the earth by a bit attached to a hollow drill pipe. This is connected with a large flat wheel, or turntable, resting on the floor of the derrick. The turntable can be made to



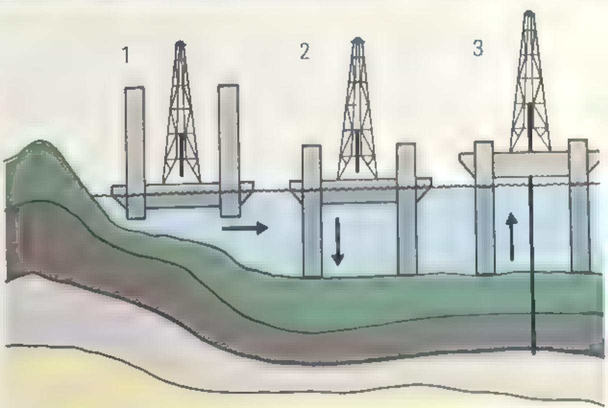
A semi-submersible oil drilling rig being towed into position. Fixed, semi-submersible, completely submersible, and movable platforms are used in offshore drilling procedures.

rotate; it is power-driven. The drill works in much the same way as a carpenter's drill, which bores holes in wood. The bits are large and heavy. They are of extremely hard steel, hollow through the center, and designed in a variety of types.

As the drill pipe cuts through the rock formations, it penetrates deeper and deeper into the ground. New sections of pipe are then fitted to the top. When oil has been reached, the drill pipe and bit are removed.

To keep the steel drill bit from overheating, a stream of mud is constantly forced down under pressure through the drill pipe and the hollow center of the bit. This mud is of a very special kind, made by mixing certain clays and chemicals with water.

After the mud passes through the hollow center of the bit, it returns outside the bit and pipe to the surface, carrying fine rock shavings with it. This serves to plaster the walls of the deepening hole, helping to prevent cave-ins. When the gas, oil, and water are finally reached, the mud holds

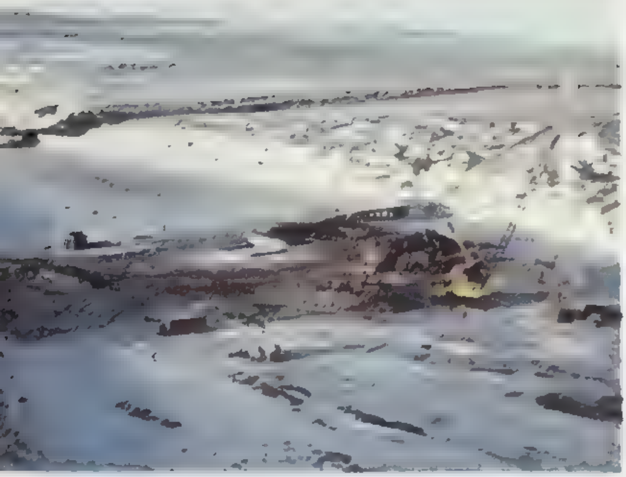


Setting up an offshore drilling operation. The drilling equipment is transported on a movable platform. (1) The legs of the platform are raised during the transport. (2) Once at the drilling site, the legs are extended to the bottom. They then support the drilling apparatus. (3) The platform is then raised a little above sea level and the drilling pipe is driven down.

back the pressure so that the flow can be more readily controlled.

OIL FLOW

As the borehole goes deeper into the earth, its sides are lined with steel pipe, called casing. Each length of pipe fits into



Alyeska Pipeline Company

The Alaska pipeline stretches nearly 1,300 kilometers from the oil fields of the North Slope to the Gulf of Alaska. Besides crossing Arctic tundra, the pipeline crosses several rivers, like the one above.

the one above it as the well extends farther downward. Then, when the required depth has been reached, a special kind of tubing, about five or six centimeters in diameter, is lowered through the casing until it runs the entire length of the well. The space between the tubing and the c... is sealed, so that the oil has to go throug... the tubing to get to the surface. Valves a... meters attached to the top of the tubin... ntrol and measure the flow of the oil. (...narily the natural pressure is enough to ... a newly drilled well flow. If, as someti... happens, there is not enough pressur... mps are used to bring the oil up.

As the oil and gas rise t... the surface, the pressure grows ... and this causes the two substances, ...ch have been in solution, to separate ... e top of the well the mixture passes int... parator, which completes the process ... that the gas-free oil may be piped i... athering tanks. If there is not very m... gas, it is often burned at the well. If, h... er, there is a great deal of it in an oil fi... is gathered and piped from the differ... ells to a natural-gas plant, where it is p... ssed and broken down into different ty... of gases. Some of these may be sent b... o the oil wells to keep up the pressure... ers may serve to make carbon black an... er products, or may be fed to main ... mission pipes and eventually used ... cooking, heating, and other fuel purpose...

If you have ever seen a... field, or

Exxon

Drilling rigs are carefully used and maintained by skilled operators, such as these workers in Malaysia.

even pictures of one, you will have noticed the number of large storage tanks clustered together in what is called a *tank farm*. These may run in size from a few hundred to several thousand barrels capacity, according to the production of the wells. In the really big tank farms, it is quite common to see tanks of 55,000- and 80,000-barrels capacity. Other groups of storage tanks may be seen at key points along pipelines, at ports where oil is loaded on tankers, and at the refineries to which crude oil goes to be processed for the market. An enormous amount of crude petroleum is constantly kept stored in such tanks in all parts of the world.

TRANSPORTING OIL

Transportation is a vital factor in the petroleum industry. In the early days, when the refineries were near the oil fields, oil in its various forms was readily transported in barrels by wagons, barges, and railways. In recent years, however, great oil fields have been developed in regions far away from the centers of population and industry. The crude oil taken from these fields is carried to refineries near the big markets by pipeline or tanker, depending upon whether it is being moved overland or by water. Railroad tank cars and even trucks are sometimes used to carry crude oil from the fields that cannot be reached by pipelines.

The oil tanker is of great importance in transporting crude petroleum, not only because that is the only way to take the petroleum across seas and oceans but also because it is by far the cheapest method of transporting large quantities. Oil from the producing U.S. states along the Gulf Coast is often carried by tankers to East Coast ports. Lake tankers transport oil from Canadian pipeline terminals through the Great Lakes. Great strings of barges float down the inland waterways of the United States, bound for southern and western refineries.

Tankers of tremendous size today sail the seas. Displacements of hundreds of thousands of metric tons are not unusual. One such giant ship can carry millions of barrels of oil at a time. Extremely large tankers are known as *supertankers*. They are cheaper to operate than smaller tankers but pose special problems. Existing port facilities cannot accommodate such large ships, and special deepwater offshore ports have to be built. The oil is then piped from this offshore port to tank farms on shore.

Tankers are built with many safety and fire-prevention devices and sophisticated navigational equipment such as radar, sonic depth finders, and gyroscopic compasses. Accidents do occur, however, and those involving very large tankers often cause widespread damage. The tens of thousands of barrels of oil that can spill out from such a tanker can seriously affect the natural environment of a region.

PIPELINES

We have seen that pipe of one sort or another is used to convey oil from the time it leaves the underground reservoir on its journey to the surface of the earth. Pipes carry it from wellhead to gathering tank and from gathering tank to storage tank.

The major oil-producing nations have built a total of many hundreds of thousands of kilometers of oil pipelines. In the United States, one famous example is the Little Big Inch, built during World War II to carry oil from the Texas fields to New York. It is now carrying natural gas. A long, controversial pipeline has been constructed across the rugged Alaskan landscape. It brings oil down from Prudhoe Bay in the northern part of Alaska.

Canada and the Soviet Union are also important pipeline builders. In Canada, the Edmonton-Great Lakes line that transports oil from the Alberta oil fields to Superior, Wisconsin, stretches more than 3,000 kilometers. It passes through the Canadian provinces of Alberta and Saskatchewan on its long journey to Wisconsin. In the Soviet Union, pipelines stretch across parts of the rough Siberian terrain.

A number of pipelines have been built and are under construction in the great oil fields of the nations of the Middle East. For example, pipelines from the Kirkuk oil fields in Iraq stretch across the desert to a terminal in Tripoli, Libya, on the shore of the Mediterranean Sea.

Steel pipe used for the Alaska pipeline was carefully tested before it was buried in the permafrost.

Alyeska

REFINING

The crude petroleum taken from oil fields must be suitably refined before it can be used by man. The modern oil refinery is an amazingly complicated affair, even just to look at. The larger plants cover great areas and seem at first sight to be veritable jungles of tall steel towers, enormous metal spheres, and vast furnaces, entwined with endless lengths of pipe. Oil refining is really a big chemical-engineering industry. Its basic processes are distillation and cracking.

The *distillation* of petroleum liquids is a complicated process. Some of these liquids boil at temperatures below 20° Celsius; others will not boil until the temperature is 315° Celsius or even higher. The distillation apparatus that is used at the present time is called the continuous-process type. The crude oil is pumped through a pipe that winds round and round a heated chamber. By the time the oil has reached a temperature of about 340° Celsius, much of it has turned into vapor. The vapor-liquid mixture then passes into the lower part of a tall steel tower called a *fractionating* tower, or fractionator, because in it the oil is separated into different fractions, or groups. Among these fractions are gasoline, kerosene, heating oil, and lubricating oil.

The fractionating tower may be as much as thirty meters high. It has perforated still trays set horizontally in it. They are spaced from 25 to 60 centimeters apart all the way to the top. Steam is usually introduced into the bottom of the tower to make the separation of the different fractions easier.

The hot oil vapor passes through the different perforated trays on its way to the top of the tower, becoming cooler as it rises. The hydrocarbons with the highest boiling point condense on the bottom trays. Those with the second highest boiling point on the next trays and so on to the top. The heaviest fraction—the so-called residue—is drawn off as a sluggish liquid from the bottom of the tower for use as heavy fuel oil or asphalt. Higher up on the column, lubricating oil condenses on the trays and is led off in liquid form. At a lower temperature come fuel oils, including gas oil, light heating oil, and light diesel fuel. Kerosene condenses still higher in the column at an even lower temperature. Gasoline collects at the

top. Uncondensed gases are piped from the top of the fractionating tower for further processing.

The other important process, called *cracking*, was developed to increase the amount of gasoline that could be obtained from the crude oil. This is done by actually breaking the molecules in the heavier part of the crude oil into the lighter molecules required for gasoline. After the cracking process the oil is redistilled in order to separate out the gasoline that has been formed.

Several different methods of cracking have been developed. In thermal cracking, the bonds between carbon atoms in molecules are broken by the action of heat alone. This method was developed about 1912 and is still employed. The major cracking process today, however, is catalytic cracking, in which a finely granulated catalyst is used. A catalyst is a substance that can change the rate of a chemical reaction without being affected itself. Petroleum vapors are mixed with the catalyst and are led to a unit called a reactor. Here a chemical reaction takes place at a high temperature. The heavier hydrocarbons are broken down into lighter ones. The spent catalyst then passes to another unit—the regenerator—where carbon deposits are removed from it. It is then ready to be used again in the cracking operation.

Research has found a number of methods of taking the hydrocarbon molecules apart and rearranging them to fit particular purposes, such as forming special kinds of gasoline. One process is called *isomerization*. It is used to rearrange the carbon and hydrogen atoms in the molecules into a pattern that will make a gasoline engine work more smoothly. In another process, called *hydrogenation*, hydrogen atoms are added to molecules that are deficient in these atoms. *Alkylation* is a method used to join together molecules of natural and cracked refinery gases. In the process of *polymerization*, smaller gaseous molecules are united to form larger ones—quite the reverse of cracking.

PETROLEUM DERIVATIVES

Thousands upon thousands of products of every description are derived, directly or indirectly, from crude petroleum. We can give only a sketchy account of the more important ones here.

Gasoline is the petroleum product in greatest demand; 45 per cent of the total yield of crude petroleum goes into the production of this fuel. It is a combination of different hydrocarbons. Motor vehicles on highways and roads consume about nine tenths of all the gasoline that is produced; the rest is used by airplanes, tractors, and various types of equipment. Fuel for jet planes is primarily a mixture of gasoline and kerosene.

Kerosene is a light and volatile liquid fuel derived from petroleum. As late as 1909, it made up 33 per cent of the total petroleum-production volume; the percentage has since dropped to about 3. Kerosene was formerly used chiefly to provide light. It now serves mainly as a fuel for cooking and for operating space-heating installations and farm equipment. It is also used, as we have noted, in the fuel mixture for jet planes.

Diesel fuels have been in greatly increased demand in recent years. Diesel engines using these fuels are to be found in ships of every size, railway locomotives, buses, trucks, automobiles, and installations for generating electricity. Over the past few decades the demand for diesel fuels increased from tens of millions of barrels to hundreds of millions of barrels yearly.

Light fuel oils are used in automatic household-heating burners and in small commercial-heating units. They also serve as smelter fuels and for other purposes. A substantial part of every barrel of crude petroleum is used for light fuel oils.

Residual fuel oils—heavy fractions of crude petroleum—are viscous, or slow-flowing, fuels. They are used in specially designed burners for commercial heating, for marine and railroad steam engines, and other purposes. Residual oil fuels are, in general, the cheapest petroleum fuels.

Lubricants generally make up only a rather small part of the total of petroleum products. They are extremely important,

however, since the moving parts of so many different kinds of machines require oiling. There are lubricants for general-purpose machinery, steam turbines, textile-mill spindles and looms, steam-engine cylinders, and, in general, for every place where a wheel, gear, or shaft rotates.

Greases are important in servicing hard-to-reach bearings in high-temperature operations and in bearing housings that cannot be made oiltight. They are also used where the dripping or splashing of fluid lubricants might contaminate products.

Wax is mainly extracted by chilling, filtering, and washing lubricating oil fractions. The principal use for paraffin wax is in packaging. Wax serves to waterproof and vaporproof milk containers and wrappers for bread, cereals, and frozen foods. It is also used in the preparation of molds for dentures and for the casting of intricate parts of machinery.

Asphalt is obtained as a residue from the refining of crude oil. It serves chiefly for roofing composition and for road surfacing.

Petroleum coke is a by-product of cracking and destructive-distillation processes. It is used largely as a fuel but has other applications. It serves in the refining of various metals, the manufacture of calcium carbide (from which acetylene gas is made), and the production of abrasives and materials with high heat resistance.

Carbon black is a by-product of the cracking process. It is used in the manufacture of automobile tires and other rubber products and of printing ink, paints, phonograph records, and so on.

Liquefied petroleum gases are stored and handled under pressure to keep them in a liquid state. They are used widely as cooking fuels in areas not served by utility systems. They also serve in refrigerators, water heaters, space heaters, and furnaces. They are often added to manufactured gas in order to enrich it. Liquefied petroleum gases play an important role on the farm. They heat incubators and brooders, sterilize milking utensils and other equipment, dry fruits and vegetables, and prevent frost damage.

Petrochemicals are the great number of organic chemicals and some inorganic chemicals derived from crude petroleum and natural gas. Among the organic petrochemicals are ethylene, propylene, butylene, isobutylene, cyclohexane, and phenol. The inorganic ones include ammonia and hydrogen peroxide.

Secondary petroleum products include numerous products derived from petroleum, and their number is increasing yearly. Most synthetic detergents are made from petroleum products. Two of the more important ingredients in the manufacture of synthetic rubber are the petroleum-derived chemicals butadiene and styrene. Among the synthetic fibers made from petroleum or its derivatives are nylon, Orlon, Dacron, Dynel, and Acrilan. These are all considered plastics. Many other plastic products are derived from petroleum. They include polyethylene "squeeze bottles," adhesives, plastic-based paints, garden hose, draperies, upholstery, luggage, and piping. In addition to these manufactures, petroleum yields such secondary products as floor wax and furniture polish, disinfectants, antiseptics, shampoos, vanishing and cold creams, hand lotions, lipstick, rouge, nail lacquers, polish removers, ointments, and drugs.

DISTRIBUTION OF PETROLEUM PRODUCTS

Certain refineries in the United States distribute their products directly to their customers. In many cases, wholesalers buy from refineries in bulk quantities in order to market petroleum products to resellers and consumers. These "bulk-plant operators," as they are called, receive shipments by tank car, truck, pipeline, tank, or barge. They keep adequate supplies on hand in storage tanks and they operate extensive transportation equipment. Bulk-plant operators supply service stations, commercial consumers, public utilities, transportation companies, and factories. In rural areas, they deliver oil products to farms by tank truck from the bulk plant or terminal.

Retail distribution of oil products is carried on on a vast scale by service stations throughout the country. Originally,


Exxon

Oil shale a rock that can be made to yield liquid fuel. There is a large reserve of oil locked in shales, but the mining and processing of shales are not as yet economical

the refiners who manufactured petroleum products owned and operated these stations. In time, the hiring and supervising of people in hundreds of scattered stations throughout the country proved to be a major problem. As a result, many companies began to lease their stations to independent dealers. Today the great majority of all U.S. gasoline service stations are owned and operated by independent local businessmen.

The heating-oil dealer is another retail distributor of petroleum products. In most areas, the dealer maintains bulk-plant installations. Certain heating-oil dealers, however, have no storage facilities of their own, but operate out of the bulk plants of their suppliers, providing only home and business delivery.

WORLD PRODUCTION AND RESERVES

The United States has been the world's biggest oil producer for a century or so. For almost 90 years, it was self-sufficient in petroleum, producing enough for its own needs and exporting to other countries as well. In 1948, however, the United States became a net petroleum importer. That is to say, it imported more petroleum than it exported. The 1973 Arab oil embargo and subsequent increases in oil prices have led the United States to aim for increased production of domestic oil. The Alaskan pipeline was opened in 1977, and, once filled with 9 million barrels of oil, it began carrying 1.2 million barrels daily to the south coast.

The major petroleum producers are listed here in order of their production: the Soviet Union, Saudi Arabia, the United States, Mexico, Venezuela, China, the United Kingdom, and Indonesia.

The world's petroleum resources are not readily renewable like other natural resources that we possess—the crops that provide us with food, the water that we drink, the air that we take into our lungs. It is true that the natural petroleum-making process that we described in the first part of this article is still going on. But this process is so slow compared with the rate at which we are using up petroleum that we must regard petroleum as an asset that cannot be replaced in the foreseeable future once it has been all used up.

However, there are still large petroleum reserves in the world. Estimates vary considerably, but the Middle East is believed to hold about 55 percent; North America, 14 percent; Eastern Europe, including the Soviet Union, 10 percent; Africa, 8 percent; and Asia, 6 percent. Prospecting for petroleum may turn up new reserves in years to come. Great quantities of petroleum products can be derived from natural gas. We can also add to our stores by distillation from oil shale and tar sands, although the mining and processing of these sources are expensive. The conservation of even these exotic sources of petroleum is necessary, since the supplies are limited.

COAL

by Christopher J. Bise

People have known for many centuries that coal is a mineral that burns. Only within the past two hundred years or so, however, has it come to play such a vital part in the world's work. Today it is an important source of power, particularly as a fuel for the steam engines that generate electricity. It is used for heating purposes. When converted into coke, it is used in the manufacture of steel and in the processing of many metals. It can be made to yield both gaseous and liquid fuels. It has also become a precious source of chemicals.

Coal is a mixture of substances. It contains volatile matter—materials that can be easily vaporized—and moisture. It has a varying amount of fixed carbon, the solid part that burns after the volatile matter and moisture have been driven off. There is also a certain percentage of ash. This is the material that remains after burning has taken place.

Coal consists of the remains of plants that have undergone a series of far-reaching changes. When we look at small pieces of coal under the microscope, we can often make out the fibers and spores of the plants from which the coal came

PLANT TO COAL

Scientists have worked out the stages that plants go through to become coal. In the first stage, green plants make their own food. To do this, they need light energy.

All green plants contain chlorophyll. This is the substance that enables the plant to make food. The chlorophyll combines carbon dioxide from the air and water from the soil, to produce glucose, a kind of sugar. It also produces oxygen. Some of the glucose is used directly as a source of chemical energy. The rest is converted into other

Dept. of Energy

A giant scraper, or "dirt wagon," scrapes away the shallow layer of dirt covering a coal seam, in a strip-mining operation

chemical compounds. These carry on the processes of growth and reproduction. Glucose and the substances derived from it are all compounds of carbon. They contain, locked within them, the energy from the sun.

Ordinarily, the carbon compounds made by the plant break up when it dies. They change into simpler substances. The solar energy that had been stored up in them is no longer available. In a bog, however, the stagnant water, deficient in oxygen, prevents the process of decay from going beyond a certain point. The partly decayed dead plants sink farther down into the bog. Other plant remains accumulate on top of them. In time, they become compressed and form the spongy mass called *peat*. This process is continually going on in bogs in various parts of the world. In some places, the peat is dug out, dried, and used as a fuel, as a fertilizer, and in several other ways. Peat represents the first stage in the change of dead plants into coal.

There was a period in the earth's history, about 250,000,000 years ago, when an unusually large amount of coal began to form, as peat. This era has been called the Carboniferous, or coal-bearing, period. Some geologists divide it into two separate periods, the Mississippian and the Pennsylvanian. Most of the high-grade coal deposits are to be found in the strata of the Pennsylvanian period.

Geologists believe that a large part of the land area was low-lying at that time. It was covered by vast swamps, standing at or slightly above sea level. The plants that grew densely in the swamps were very different from those covering the earth today. Some were like the modern ferns, horsetails, club mosses, and scouring rushes, but generally they were larger.

The remains of these plants accumulated in the waters of the bogs. Peat was gradually formed through the centuries, milleniums, and millions of years. Eventually the bogs were buried under sand and mud. Then the earth's crust buckled and folded and moved. The peat deposits underwent terrific pressure, which also generated heat. The result was a series of changes in the course of which the peat was changed into coal. This end-product has, stored within it, much of the original energy derived from the sun. This energy is released when the coal is burned.

It is hard to say when the coal-making process for a given deposit was completed. The time range may have been from half a million years to many millions of years. The chief factors were the degree of compression and heat.

The coal beds of today are separated from each other by several thicknesses of sedimentary rock. This rock is made up of layers of sand, mud, and lime. Fossils of various kinds occur in the surrounding rock layers.

Since dead plants are still being made into peat in various swampy areas, the question might arise as to whether or not this peat will turn to coal eventually. Although this is a difficult question to answer, it should be pointed out that coal beds have been formed during various ages of the earth. Presently, the Dismal Swamp area of southeastern Virginia is typical of the conditions needed for the formation of coal.

The same basic process that forms coal also produces peat, a spongy material dried and used for fuel in Ireland and other parts of the world

TYPES OF COAL

There are four ranks, or types, of coal. Ranging in the order of their development from peat, they are lignite, subbituminous coal, bituminous coal, and anthracite. The four ranks are not clearly different from one another. Their composition may vary widely in different places.

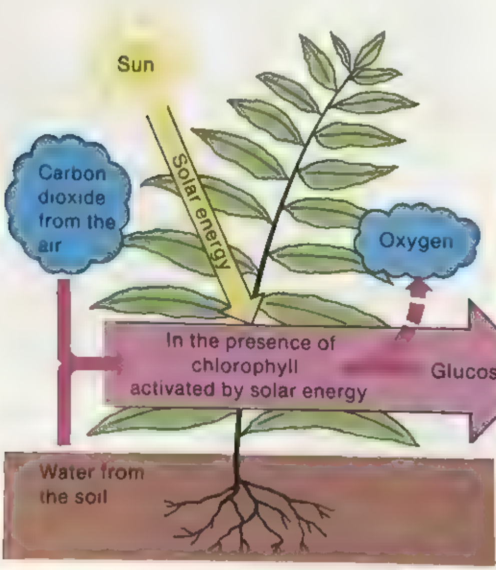
The lowest rank of coal, *lignite*, shows more or less clearly the structure of the original plant matter, including the woody element. Lignite (from the Latin word *lignum*, meaning wood) has the lowest percentage of fixed carbon of all the four ranks. It also has the highest content of volatile matter and moisture. It ranges in color from light brown to very dark brown. The light brown variety is sometimes called "brown coal."

Subbituminous coal is black and shows no traces of woody substance to the naked eye. (The name "bituminous" comes from the Latin *bitumen*, meaning "pitch.") The word "bitumen" refers nowadays to several inflammable mineral substances, such as asphalt, but it is no longer applied to coal. Subbituminous coal may have up to 40 per cent fixed carbon and as much as 25 per cent moisture.

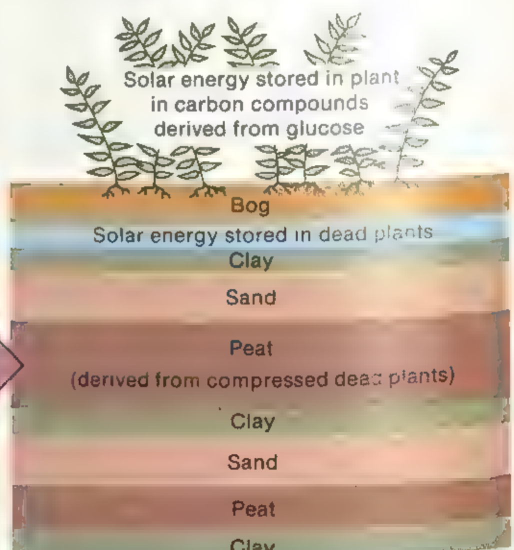
The fixed-carbon content of *bituminous coal* may exceed 70 per cent. Its moisture content is less than 15 per cent. Bituminous coal is also known as soft coal. It catches fire easily and burns with a yellow flame. It produces smoke and odor, depending upon the amount of ash and sulfur that it contains.

Anthracite (from the Greek *anthrax*, meaning "coal") is the highest rank of coal. It has very little moisture and it may have over 90 per cent fixed carbon. Kindling slowly, it burns longer than other kinds of coal. Anthracite produces a blue flame. It gives off no smoke and very little odor because it is basically low in ash and sulfur content. It is found in rock strata that have been greatly folded during mountain-making in the past. The lower ranks of coal occur in layers that have been only slightly disturbed by earth movements.

Stages in the transformation of plants into coal. Green plants, growing in bogs, combined carbon dioxide and water (in the presence of chlorophyll activated by sunlight) and formed glucose and oxygen.



When the plants died, their remains (containing carbon compounds derived from glucose) underwent only partial decay. In the course of time, they were compressed into a spongy mass known as peat.



USE OF COAL IN TIMES PAST

Remains of coal fires have been traced to prehistoric times. Perhaps primitive people, seeking stones to build a hearth, used coal for this purpose. They found, to their amazement, that the "stone" itself caught fire. Coal was mined in China and Greece centuries before the birth of Christ. It is mentioned in the Old Testament. Its properties were described by the Greek philosophers Aristotle and Theophrastus in the fourth century B.C.

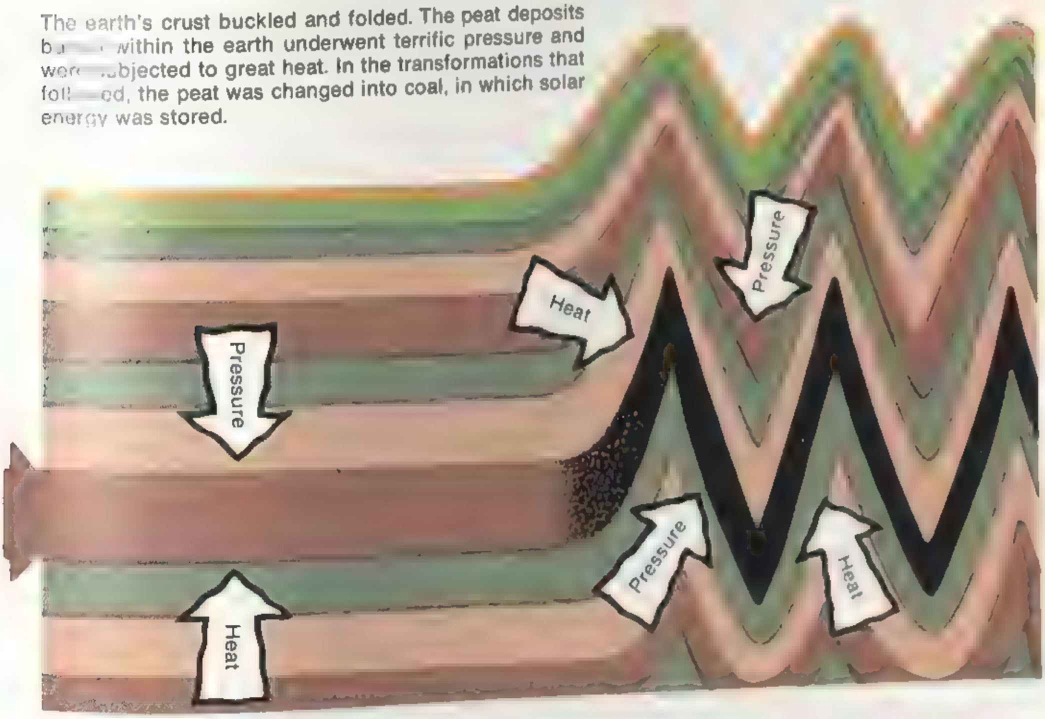
Coal was mined in Germany as early as a thousand years ago. It was mined in England by the thirteenth century. Blacksmiths found the hot flame of the mineral excellent for heating purposes. Poor people preferred coal to wood as a fuel, because coal was cheaper. However, it was burned so inefficiently that it gave off heavy smoke and disagreeable odors.

Coal was not in great demand in the American colonies for heating purposes because wood was plentiful. The coal that was used in those early days generally was imported. The first coal mine in the colonies was opened near Richmond, Virginia, in the eighteenth century. More mines were opened up after the American Revolution, and the United States soon became independent of foreign coal.

It was not until the beginning of the Industrial Revolution in the mid-eighteenth century that coal came into its own as a major source of energy. The rise of the railroads in the first half of the nineteenth century marked a milestone in the history of the coal industry. The mineral could now be carried easily to markets in distant places. Locomotives burned large amounts of coal themselves.

In the years that followed, coal became a necessary fuel for heating and as a source of power in many countries. As time went by, other important uses were found for it. Nations that lacked coal or that were unable to import enough of it did not develop so rapidly. In the twentieth century, coal has had its ups and downs. It is still, however, important as a fuel and as a raw

The earth's crust buckled and folded. The peat deposits buried within the earth underwent terrific pressure and were subjected to great heat. In the transformations that followed, the peat was changed into coal, in which solar energy was stored.



material. It is becoming more important as the supply of oil declines and its cost rises. There is research on better and cheaper means of using coal. Researchers are also trying to decrease coal's harmful effects on health and the environment.

COAL MINING

The first humans to use coal probably picked pieces off the ground. They probably also knocked chunks of it loose from seams that out-cropped—that is, appeared on the earth's surface. Seldom is it so easily available. In most cases miners must dig through the covering of soil and rock in order to get at the coal seams. Then, coal mines can be opened.

There are two kinds of mining. If the coal deposit lies close enough to the surface of the earth, the method called *strip mining*, or *open-pit mining*, is used. If the coal is deeper, *underground mining* is used.

SURFACE MINES

In the strip-mining process, the overburden of soil and rock is first removed. It is removed by big power shovels, draglines, or other kinds of earth movers. After the coal seam has been exposed, it may be broken up by explosives for easier handling. The coal is then loaded into trucks by smaller power shovels.

A bucket-wheel excavator may also be used to remove the overburden covering the coal. This huge machine weighs over 2,000 metric tons. It uses an eight-meter wheel to pick up earth and removes it on conveyor belts at the rate of almost a metric ton a second.

An offshoot of surface mining is *auger mining*. This is applied in hilly areas where the overburden is too thick to be profitably removed. After the face of the seam has been exposed, huge augers, from about one-half to two meters in diameter, bore horizontally into the seam. The loosened coal flows out along the auger and onto a conveyor, which dumps it into a truck. Auger mining is more productive than any other type. However, sites for this type of mining are limited.

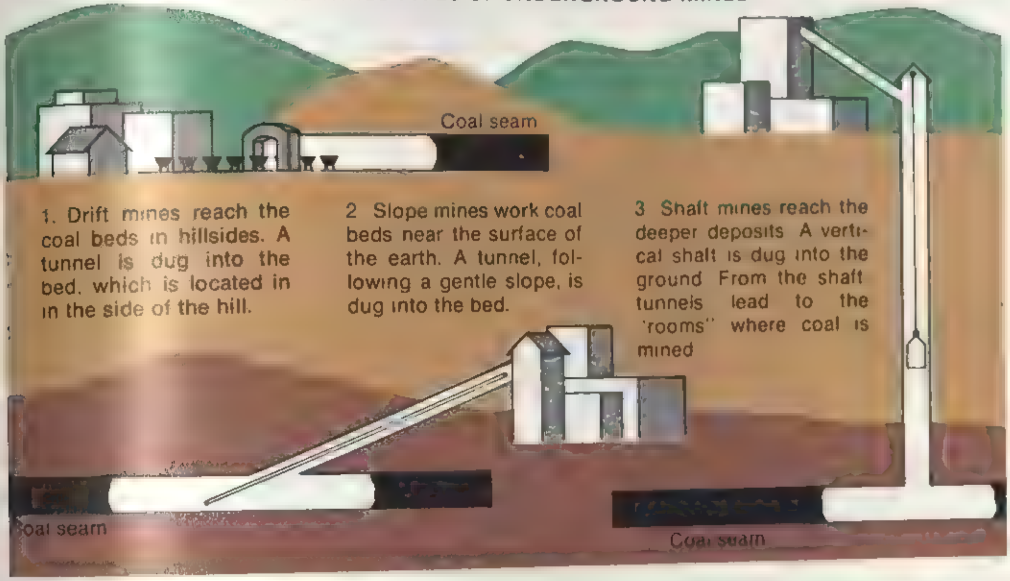
UNDERGROUND MINES

Approximately 40 per cent of the annual coal production of the United States is obtained from underground mines. There are three kinds, based upon the manner in which the coal is reached. *Slope mines* are used to work coal beds which are near the surface of the earth, though not so near as in the case of strip mines. A tunnel is dug into the ground, following a gentle slope, until it reaches the coal bed. *Drift mines* reach coal beds in hillsides. The entrance to the tunnel is at a place where the coal seam has been exposed. *Shaft mines* are used to get at the deeper deposits. Vertical shafts, at least 30 meters deep, are dug into the ground. In the United States, the shafts range in depth to beyond 500 meters. In

Dept of Energy

Strip-mining, or open-pit mining, reaches coal deposits lying close to the surface. The coal is exposed, broken up, and removed.

THE THREE TYPES OF UNDERGROUND MINES



Europe, they may be more than 1,000 meters deep. From the lower parts of the shafts, a network of tunnels leads to the *rooms* or the faces from which the coal is dug. The rooms are known as *breasts*, *chambers*, or *chutes* in anthracite mines. Elevators, called *skips*, transport miners to and from the surface and *workings*—the place from which coal is extracted. The skips also bring up coal.

Underground mines generally have quite extensive transportation systems. In the *haulageways* of underground coal mines, low-slung electric locomotives, powered by overhead trolleys or big storage batteries, transport open cars along rails. In still other mines, belt conveyors are used. Trackless shuttle cars, driven either by electricity or batteries, are the typical vehicle for hauling coal from the workings to the main haulageways.

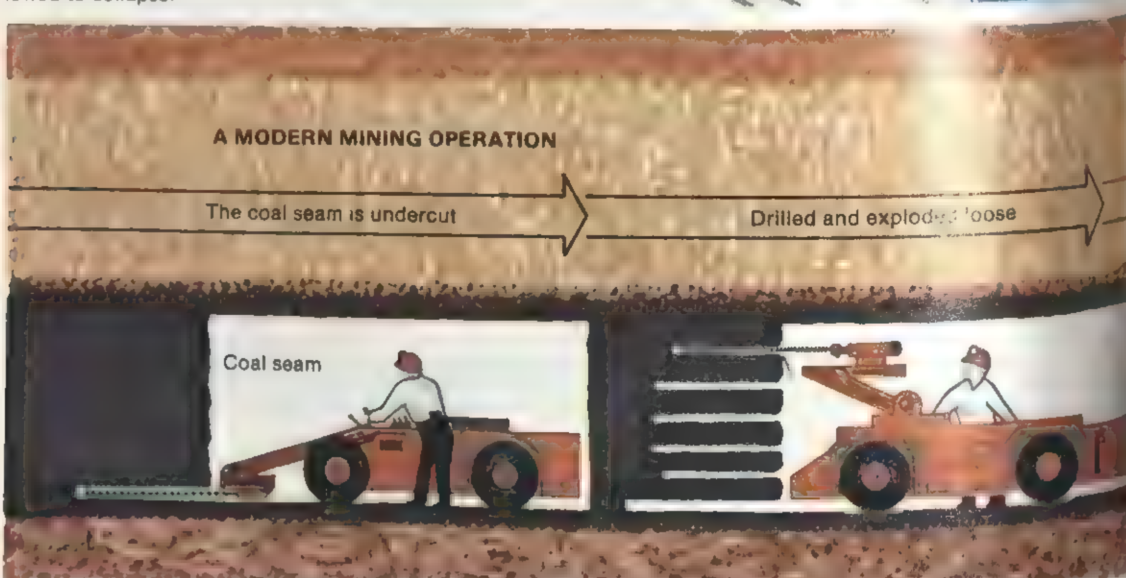
There are three basic forms of underground coal mining—*room-and-pillar*, *shortwall*, and *longwall*. In the first method, rooms are dug out of the coal bed. Isolated pillars of coal are left at intervals to support the roof. They are always aided by artificial roof supports. This method is in general use in the United States. The room-and-pillar system would be wasteful, of course, if the coal pillars are left standing after the rest of the coal has been obtained from the workings. Generally, therefore, the pillars of such a mine are removed—a process called *robbing*—and the roof is allowed to collapse. Temporary roof supports are usually set in place while the coal is taken from the pillar.

The room-and-pillar method has many modifications, particularly where mining machinery has been introduced. For example, ordinary room-and-pillar mining uses a cutting machine, a drilling machine, explosives to blast the coal, and a loading machine to load the fragmented coal into waiting shuttle cars. On the other hand, continuous room-and-pillar mining combines all the above steps, except haulage, into one machine—a *continuous miner*—which rips the coal from the deposit.

The longwall system of mining is so called because the working face is quite long. In this particular case, the roof is propped up by steel supports. The coal is mined by either a shearing machine, which cuts the coal with rotating drums laced with cutting bits, or a plow. This mining method is widely used in Europe, but contributes only about 3% of U.S. coal production. Shortwall mining is almost identical

ROOM-AND-PILLAR METHOD OF UNDERGROUND MINING

Plan of a typical subsurface mine where the room-and-pillar method is applied. When rooms are dug out of the coal bed, isolated pillars of coal are left to support the roof. The pillars themselves are mined later on and the roof is then allowed to collapse.



to longwall mining except that the working face is shorter. The mining machine is a continuous miner.

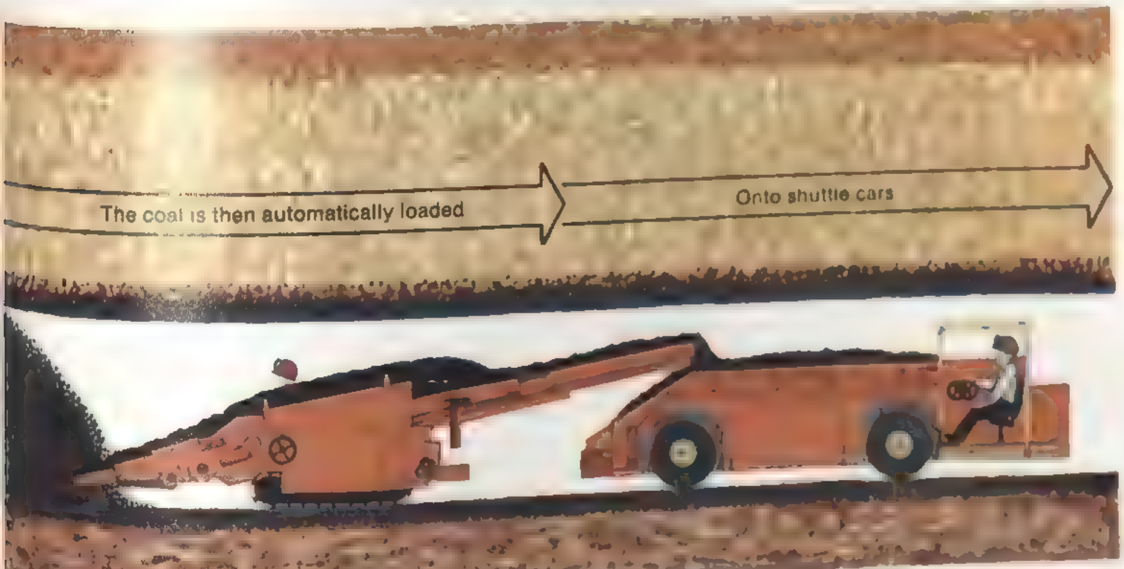
Although longwall mining contributes only a small portion of the U.S. coal production, its potential for future applications is promising. As time goes by, the coal seams that are easy to mine will become fully extracted. Thus, deeper coal seams under poorer natural conditions will have to be mined. One of the major advantages of longwall mining is that it can deal with these difficult conditions much better than room-and pillar systems. Further, longwall mining permits greater recovery of the seams being mined and, therefore, better conservation.

Longwall mining, however, has one major disadvantage—it is very expensive. For example, one complete longwall section, including the roof supports, mining machine, and haulage equipment, can cost approximately $6,000,000 to $12,000,000. This is about ten times as expensive as a typical room-and-pillar section. Thus, future use of longwall mining in the United States may depend mainly on whether or not it becomes economical.

Formerly, underground mining was a fairly simple operation. Miners dug the coal with picks. When necessary, they blasted the coal faces with explosives. The coal was then shoveled into cars. The cars were hauled to the surface, often by mules. This method has been generally replaced in U.S. mines by more effective systems, in which machinery plays an important part. Generally, the first step in conventional roof-and-pillar mining is to undercut the face at the base. This means that a miner cuts a slot in the seam. There are various types of electrically-powered cutting machines. Sometimes, the cutting machines remove coal from the sides, the top, or across the middle of the bed. After the seam has been undercut, *shot holes* are drilled into the working face. Explosive charges are then inserted and set off by electricity.

Dynamite was once widely used in coal mines. But it is very dangerous. Several other explosives have been substituted for it. In the United States and certain other countries, only "permissible" explosives may be used. The name is applied to types that burn with a shorter flame and at a lower temperature than dynamite. Cylinders containing liquid carbon dioxide or compressed air are sometimes used.

Several devices based on hydraulic principles are now being tested for remov-



A "continuous miner" bites into the face of a coal seam, rips out as much as twelve tons of coal a minute, and loads it into shuttle cars.

ing coal from the seam and carrying it to the surface of the mine. Mining coal by impact from a water jet ("hydraulic mining") is common in the Soviet Union and Japan. It has recently been introduced in a mine in western Canada. This method shows great promise, particularly in coal seams greater than six meters in thickness.

Current research in mining equipment has been directed toward automation and remote control. Most injuries in underground coal mines occur in the immediate area of the faces being mined. The design of equipment to allow the removal of miners from this dangerous area has been a major concern.

MOVING COAL IN THE MINE

Once the coal has been freed from the seams, it must be hauled through the mine.

A [illegible]

Then it has to be brought up to the surface. Some of the transportation methods in use have already been mentioned. To pick up the loosened coal, in the conventional mining process, different loading machines are often used. Mobile loaders, mounted on caterpillar treads, sweep up the loose coal with steel arms. A conveyor within the machine carries the coal back and drops it into a shuttle car or conveyor belt for the trip to the mine's main haulage system. There are several other kinds of loaders of various sizes and shapes. They are adapted to either room-and-pillar, longwall, or shortwall mining.

As mentioned earlier, the machine called the continuous miner not only extracts coal from the working face (eliminating the steps of cutting, drilling, and blasting). It also loads the coal. The continuous miner has cutting heads with many teeth. It "eats" its way into the coal seam tearing loose the coal and passing it to the rear of the machine. Here the coal is loaded into shuttle cars or transferred to conveyor belts. There are several types of continuous miners. Some of them can extract and load up to eight metric tons of coal per minute.

In drift and slope mines, the coal is taken directly to the mouth of the mine by cars or conveyors. In shaft mines, shuttle cars or conveyors carry the coal to other cars or conveyors running along the main haulage ways. Formerly, cars filled with coal were loaded in cages (elevators), hauled to the surface, and then emptied. Presently, in many mines, conveyor belts are used to bring the coal out. In some mines, electric locomotives haul loaded cars to a rotary dump. Here each car is mechanically picked up and turned completely over. The cars dump their contents into a bin. From there the coal is fed onto the main conveyor belt for transportation to the outside.

MINE SAFETY

There are a number of hazards in coal mining. In the early days of mining, they frequently caused disastrous accidents. Methane, a gas generated by ancient coal swamp plants when they died, often co-

lects as a seam is worked. Sometimes the amount of methane can rise to 5 to 15 per cent in a methane-air mixture. This mixture, called *firedamp*, becomes explosive and can easily be ignited. In the early mines, it was often set off by the lamps and candles used for light. If the mixture of air and methane contains more than 15 per cent of methane, there will not be enough oxygen in the air to support combustion. However the addition of even a little oxygen to the mixture can make it explosive. Hence any such concentration of methane is very dangerous.

In the future, however, methane may prove to be more of a benefit than a burden. For methane is a fuel—natural gas. Present research is being conducted on the removal of methane from coal seams before mining.

Carbon-dioxide gas is also given off by coal-bearing strata as they are worked. If enough of it collects, it is a menace to breathing. Hence it is called *chokedamp*. Carbon monoxide, a poisonous gas called *afterdamp* in mines, sometimes occurs after an explosion or a mine fire.

Another important menace is the coal dust formed when coal is broken up at the working face. Coal dust can ignite very easily if enough is floating in the air. A spark from a tool or machine may set it off.

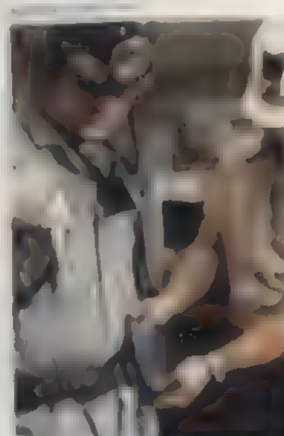
There are several other coal-mine hazards. If a mine is located far beneath the surface of the earth or below an underground stream, water may collect in large quantities. This may interfere with mining operations and even endanger the lives of the miners. Moisture condensing on the roof can cause the lower section of the roof to expand. Parts of this section may become loosened and fall as a result. There may be cave-ins as more and more coal is taken out of a seam.

Several effective measures have been taken to meet these perils. One of the early devices developed to minimize the danger of explosion was the miner's safety lamp. It was invented by Sir Humphrey Davy in 1815. In this device, the flame was enclosed in a wire gauze cylinder, capped by a double thickness of the gauze. The heat of the flame was absorbed and conducted away by the metal gauze. As a result there was no longer any danger of igniting any explosive gases in the area.

A variation of this device is also used to detect methane. If this gas is present in considerable quantities, the flame will lengthen. Also, it will flicker or go out entirely if there is too little oxygen. The safety lamp, however, is no longer the main means for detecting methane. The approved method is an on-the-spot chemical analysis of samples of mine air. This is done with a device called a methanometer. Supervisors called *fire bosses*, inspect the working areas frequently. They make sure there are no dangerous gas accumulations of any kind.

Adequate ventilation helps to keep harmful gases under control. Giant fans located near the mine mouth supply fresh air throughout the mine in large volumes. These fans, on the average, circulate six metric tons of air for every metric ton of coal that is mined. Smaller fans are sometimes used within the mine itself to keep the air moving and to dilute the gases. Ventilation networks can become very difficult, making computer design by mining engineers almost a necessity.

Water sprays help control the coal dust that is raised as the working face is cut. Spraying machines blow limestone dust (rock dust) over the roofs and floors of tunnels. The limestone dust, which is not



bins, the coal slides down sloping chutes into open freight cars. Most of the coal mined in the United States is carried at least part of the way to market in cars of this type.

Trucks and barges also serve to carry coal. Barges are used to carry it from mines located on rivers, since it is cheaper to ship by barge than by rail. Fine coal, mixed with water, is sometimes carried by pipeline.

Utilities, steel mills, and other large consumers generally keep a large supply of coal on hand. It is stored either in the open or in large silos. Anthracite and bituminous coal resist weathering very well. Lignite and subbituminous coal, however, must be protected from the weather to avoid deterioration.

USES OF COAL

Coal is used chiefly as a fuel. Lignite, subbituminous coal, bituminous coal, and anthracite all serve that purpose. Coal that is too fine for ordinary heating purposes makes a fine fuel when it is pressed together, with pitch as a binder, to form briquettes and pellets. Pulverized coal has also proved useful as a fuel. It burns as readily as fuel oil when it is blown into a furnace by a blast of air.

Coal has had increasing competition from other fossil fuels, namely oil and natural gas. The coal industry has sought to bolster the use of coal for heating by introducing devices to make heating as effective as possible. Mechanical stokers, operated by small electric motors, feed coal automatically into furnaces. Certain devices remove the ashes from the firebox automatically and deposit them in covered receptacles for safety.

At one time, coal-burning locomotives used large amounts of the fuel yearly. They have been largely replaced, in the United States, by diesel-electric locomotives. Attempts have been made to spur the use of coal by the railroads. These attempts have not been too successful. Gas-turbine locomotives burning powdered coal have been proposed but have not come into use.

In one all-important area the use of coal as a fuel is increasing. More dynamos that generate electricity are run by coal than by all the other fuels and water power combined. The sharp upward climb of the electric generating industry has improved the position of coal as a fuel.

Nevertheless, experts agree that the chief way to expand the use of coal significantly is to develop economical ways to convert coal to synthetic gas and oil. The technology to do this is available but was little developed until the late 1960's and the 1970's. Now there is intensified research on new processes to make coal gasification efficient and economical.

COKE

From coal we get the solid fuel known as *coke*. This is prepared by heating certain kinds of bituminous coal in furnaces into which air is not admitted. The more volatile constituents, such as moisture, tars, and gases, are driven off. The solid matter that remains, consisting of fixed carbon and ash, is coke.

Coal used to be coked in long rows of arched ovens. These were called beehive ovens because of their shape. The vapors and gases that resulted from coking were allowed to pass off into the air, because they were thought to be worthless. Today we know that these "worthless" gases are extremely valuable. To save them, most bituminous coal is now coked in so-called *by-product ovens*, though other types are still in use.

By-product ovens are arranged in batteries, or groups, of from 10 to 90 ovens each. Bituminous coal is loaded into an oven from the top. Then the oven is sealed and heat is applied. The solid matter that remains in the ovens is coke. It is made up chiefly of fixed carbon and ash. The gas and vapors pass through large pipes into by-product preparation units. We shall see later how these by-products are used.

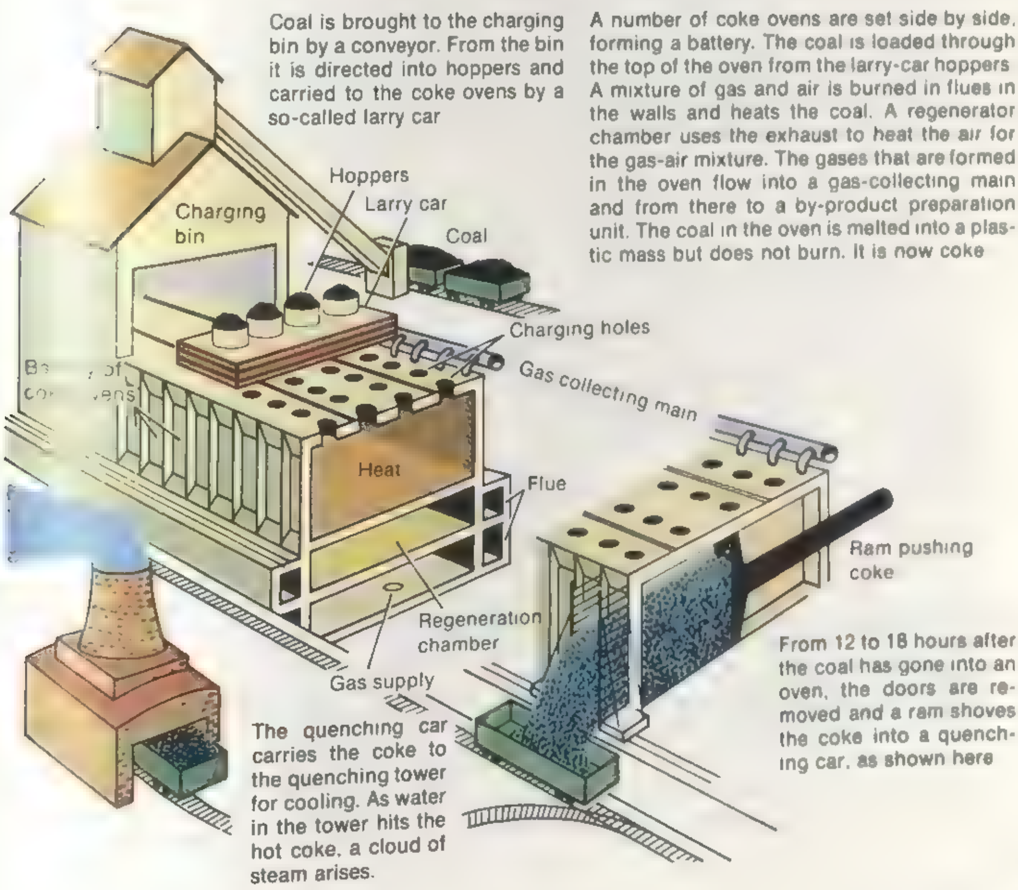
Coke is used today on a large scale as a fuel in smelting ores. Large quantities are used by the steel industry. It has been estimated that almost a metric ton of coal is used to produce the coke needed to manufacture a metric ton of steel.

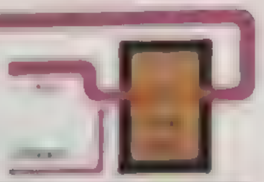
The fuel gases known as producer gas, water gas, and carbureted water gas are derived from coal. *Producer gas* is formed by continuously forcing air and a small quantity of steam through heated coke or coal (bituminous or anthracite). It is more than one-half nitrogen. It also contains hydrogen and carbon monoxide. Producer gas is low in heating value. It is used chiefly in industrial processes, including coking.

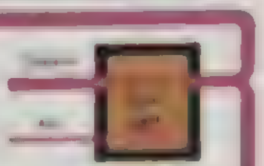
To form *water gas*, or *blue gas* as it is sometimes called, a blast of air is forced through a fuelbed of coke or coal. This raises it to white heat. Then steam is passed through it, producing the water gas. It is a mixture of carbon monoxide, hydrogen, and carbon dioxide. Air is then forced again through the fuelbed and the cycle is repeated. Water gas has over twice the heat output of producer gas, but even this is not considered enough. It is generally enriched with oil gas, derived from oil, to form *carbureted water gas*. A certain amount of tar is produced in the process. This is removed as a by-product. Carbureted water gas is a fine fuel and has been used widely in city utility systems.

Mining engineers have sought to produce fuel gas by burning coal in its seams – a process called *underground gasification*. This method is widely used in the Soviet Union. It makes it possible to use the coal in seams that cannot be mined profitably because they are too thin or too inaccessible.

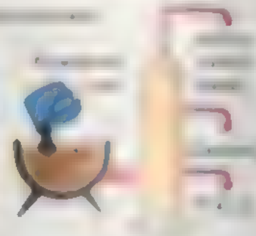
COKING BY-PRODUCT OVENS

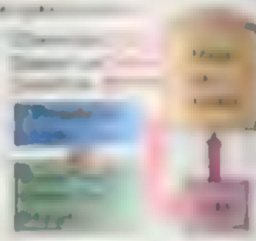






[illegible]



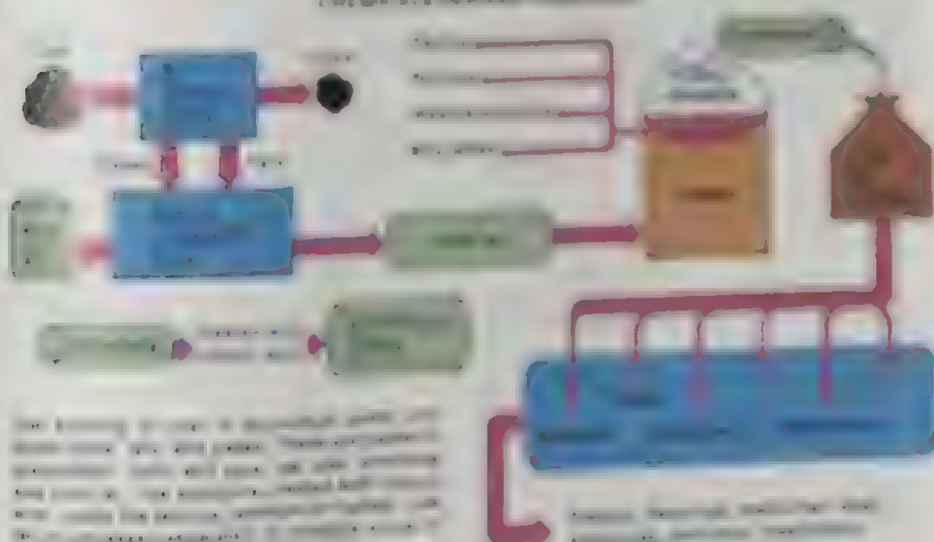


CHEMICAL DERIVATIVES OF COAL

Coal has become one of the most important sources of chemical [illegible]. The tars and gases that result from coking in by-product ovens are piped from the latter to special preparation [illegible]. Here they are made to yield fuel gas, ammonia, and coal tar. The ammonia is treated with sulfuric acid and is changed into a valuable fertilizer, ammonium sulfate.

Coal tar is the most important by-product of the coking ovens. After the tar is dried, it is heated and distilled. The vapors that arise are condensed and yield a number of oils of different [illegible]. These oils, which are known as coal-tar crudes, include benzene, toluene, naphthalene, [illegible] of the distilling process is a thick, sluggishly flowing liquid called pitch. It serves as a paving, roofing, and waterproofing compound. Mixed with small-sized coal, it [illegible]

As for benzene, toluene, naphthalene and the other coal-tar chemicals, they yield an amazing variety of products. They give explosives, such as trinitrotoluol (TNT) and [illegible]



an Gas Assn

Natural gas pipelines may be seen above ground in some remote areas

NATURAL GAS

For many years, the gases derived from coal and coke have supplied man with valuable fuel. In recent years, however, the gas industry has turned increasingly for its supplies to the vast stores of natural gas trapped within the rock layers of the earth, generally far beneath the surface.

Scientists are still not sure how natural gas came to be stored up in the crust of our planet. According to the generally accepted theory, countless numbers of tiny marine plants and animals, called plankton, were deposited on the ocean floor many millions of years ago. Their remains were covered over by layers of mud, which had been washed into the sea from the shore. As thousands and thousands of years passed, more layers were piled on. The sediments were subjected to extreme pressures and intense heat. Often they were folded and squeezed by movements of the earth's crust. The different layers turned into various kinds of rocks, some of which were porous. The remains of the once-living animals and plants were converted into gas and oil, which often occur together.

It is a common belief that gas and oil are found in huge subterranean caverns. As a matter of fact, they both occur in minute pores of such rocks as sandstone and limestone. They are held captive under great pressure by surrounding rock formations that are impervious to seepage. Finally they are released when the shifting of the earth's surface cracks the *cap rock*—the impervious rock layer above the deposits—or when the cap rock is penetrated by a drilling bit.

Natural gas has been known to mankind from a very early day, perhaps before recorded history. Ancient peoples were undoubtedly mystified and perhaps terror-stricken when they accidentally discovered natural gas seeping from the ground or rising through clefts in rocks. They noticed that when they approached such places, they often became lightheaded or lost control over their legs and spoke in disjointed fashion. Thinking that they must be in the presence of a supernatural power, they erected temples of worship on or near these sites. The famous Oracle of Delphi was one of these temples.

Sooner or later, people learned—perhaps by accident—that the gas that seeped from the ground was flammable. The Chinese made use of this property as early as 940 B.C. They piped the gas through hollow bamboo rods from the sites where it was found to the seashore, and there they burned it to evaporate the brine and produce salt.

But such commercial use of natural gas was quite rare. For thousands of years, men knew of the existence of this gas, but they thought of it as a natural marvel rather than as a marketable commodity. For example, George Washington commented wonderingly in 1775 on a "burning spring" on the banks of the Kanawha River near Charleston, West Virginia. Gas seeping from the ground in this area had been ignited and provided a natural torch.

FIRST USE AS A FUEL

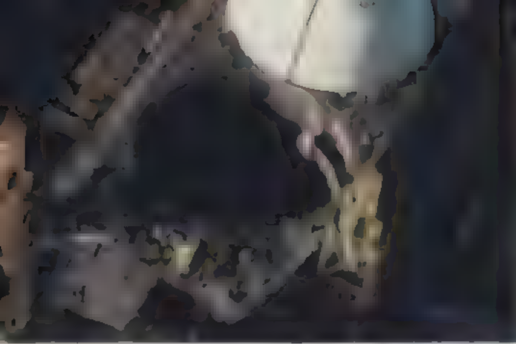
Natural gas was not to come into its own as a fuel for a great many years. Fuel experts were far more interested in manufactured gas, made from coal and, later, also from coke and from oil. Manufactured gas was the chief gaseous fuel throughout the nineteenth century. It is still in use in various communities.

Though natural gas was not a serious competitor of manufactured gas until the twentieth century, it was used on a modest scale in the United States since the 1820's. The first natural-gas well to be drilled in that country was opened up at Fredonia, New York, in 1821. The well was about eight meters deep and was "capped" with a large barrel to maintain pressure. When the Marquis de Lafayette visited the town four years later, he found it lighted with natural gas. A dinner in his honor was cooked over the gas at Fredonia's hotel.

In 1826, another natural-gas well was drilled on the shores of Lake Erie at Westfield, New York. A wooden pipeline, a little less than one kilometer long, was built to carry gas to a lighthouse at Barcelona Harbor, New York. In 1840, natural gas was used in Butler County, Pennsylvania, in evaporating brine to produce salt.

The first corporation organized to supply natural gas in the United States was the Fredonia (New York) Gas Light and Water Works, formed in 1858 to sell natural gas to business concerns and private homes. By

Offshore drilling operations are monitored from control rooms like this one.



[illegible] natural gas is transported in specially equipped tankers shown in constr[illegible] [illegible] or [illegible] right, after [illegible].

that time, however, 300 companies had already been established in the United States to manufacture gas from coal. These companies served nearly five million customers, about one sixth of the nation's population at that time.

Actually, there was still little demand for natural gas as a fuel. When the first oil well was discovered in the United States in Titusville, Pennsylvania, in 1859, producers were dismayed to find that natural gas occurred together with the oil. To get rid of the gas it was flared — that is, ignited at the wellhead and left to burn. This became a common practice in other parts of the country, too, particularly in the Southwest. Millions of cubic meters of the gas were wasted in this way.

NATURAL GAS PIPELINES

The fact that natural gas is frequently found together with oil contributed to the growth of the natural-gas industry. As more and more oil was discovered in various parts of the United States and the demand for it increased, producers sought to find effective ways of transmitting natural gas, so often found with the oil, to nearby markets. Progress was rather slow. The first "long-distance" pipeline, built in 1870, was made of white pine logs in which 20-centimeter holes had been bored. The logs were [illegible] end to end. Gas was carried about 25 kilometers in this pipeline, from West [illegible] to Rochester, New York. The project was given up as a failure after a [illegible] of years.

Iron pipe was utilized for the first time in carrying natural gas in 1872, when a [illegible] centimeters in diameter, was built from Newton Wells to Titusville, Pennsylvania. As late as 1890 natural-gas lines were still small in diameter, mostly under 20 centimeters, and they extended relatively short d[illegible].

By 1900, natural gas had been discovered in seventeen states, but the total production for that year was sold for less than \$25,000,000. Pennsylvania was then the largest gas-producing state. In the decade that followed, immense natural-gas deposits were discovered in Texas, California and Oklahoma.

Long-distance natural-gas transmission lines got their real start in 1925, when seamless, electrically welded pipe became available to the industry. Gathering and transporting natural gas now became profitable, and by 1930 the consumption of the gas had greatly increased. Expanding pipeline systems began to bring it to cities formerly served with manufactured gas. From that time, the consumption of natural gas increased phenomenally.

In the late 1940s, the gas industry in the United States acquired two vast pipeline systems — the Big Inch and the Little Big Inch, which had been built by the government to carry oil to the eastern coast. They were converted into natural-gas transmission lines. The Big Inch is still transporting natural gas. The Little Big Inch is now carrying petroleum products.

In 1940, natural-gas production in the United States came to about 90,000,000,000 cubic meters. Fifteen years later, the production rate was 300,000,000,000 cubic meters annually. Today, the gas furnishes some 30 per cent of the U.S. total fuel energy.

In spite of [illegible] great amounts of natural gas with[illegible] from wells in the last few years new [illegible]veries have added to the reserves [illegible] to man. There is, however, [illegible] controversy over just how much [illegible] gas reserves there are. In the United [illegible] they are concentrated in seven [illegible]: Texas, Louisiana, New Mexico, [illegible], Oklahoma, Alaska and California.

[illegible] NATURAL GAS

It [illegible] task to find a store of natural [illegible] earth. Prospectors—geologists, [illegible], chemists and engineers—[illegible] the gas is found in porous rock and [illegible] trapped under a layer of dense rock that is not porous. They look for such [illegible] in deserts, on mountains, in swamp[illegible] snow and ice, along the seacoast [illegible] offshore. When they find the right [illegible] place or other, a surveying party [illegible] to make an accurate map of the [illegible]. Geologists study the map closely. [illegible] to figure out, from what they can [illegible] the surface, how the rock layers be[illegible] surface lie and whether or not nat[illegible] trapped there.

Ph[illegible] and geologists now bring up their [illegible]. They explode dynamite in the [illegible]. The shock of the explosion travels d[illegible] the earth and bounces back off [illegible] layers of rock below. Inside a truck [illegible]graph detects and records these [illegible]. From the seismograph records the [illegible] can tell something about the sha[illegible] nature of the rock layers deep within the earth.

Certain layers of rock affect the [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Steve McCutcheon

Roughnecks on Alaska's North Slope bring a drill up out of a well.

these out of the drill hole, water containing clay and chemicals is pumped down the drill pipe. This watery mixture is called "drill mud." It effectively cools and lubricates the drill bit, besides bringing up the chips and pieces of rock. These fragments are carefully examined, because they tell the drilling crew what sort of rock layers the drill bit is penetrating.

When the drill bit is worn, it must be replaced by a new one. The drill pipe is pulled up out of the ground and unscrewed length by length. The sections are stacked on the ground and in the derrick. At last, the worn bit comes out of the hole, sometimes with one or more sections attached. A new bit is screwed in and it goes back into the hole, followed by many lengths of drill pipe. Drilling goes on night and day. Three crews of five men each are needed, each crew working for eight hours. All this drilling may be useless, for there may not be any gas or oil at a given place. Out of ten holes drilled, one yields gas.

When there is a rushing sound and natural gas comes roaring up, the drilling engineers and crew know that the search for buried treasure has been successful. The drill pipe and bit are now pulled up. The hole must be capped to prevent the gas from escaping and to control its flow. The device used for this purpose is called the "Christmas tree." It consists of a collection of valves. Its shape may have reminded somebody of a Christmas tree: that is probably how the name originated. Some of the valves on the "Christmas tree" lead the natural gas to instruments that indicate the pressure and supply other information. Other valves control the flow of gas out of the "Christmas tree."

Many of the same kinds of drilling methods as those described above are employed in offshore operations. Drilling costs are much higher in these operations and wells are often dug deeper. The average depth of land wells is about 1,200 meters. Offshore natural-gas wells in the Gulf of Mexico are more than twice as deep, on the average.

Most natural gas makes fine fuel just as it comes up out of the ground. A small percentage, however, contains water, sulfur, or other impurities. To remove these, the gas is passed through so-called scrubbing towers before it enters the pipelines. Since pure natural gas is odorless, a chemical odorant is added to it as a safety precaution; otherwise it would not be possible to detect escaping gas.

The hydrocarbon methane (CH_4) forms the bulk of the natural gas we burn in our homes. Natural gas also contains other valuable hydrocarbons, many of which are separated, or "stripped," from the gas before it is sent on its long journey to the consumer. The stripped hydrocarbons are used for various industrial purposes.

ESTABLISHING PIPELINES

Laying a long-distance transmission line is a job that calls for highly trained people and many powerful and complicated machines. First, engineers survey and map the pipeline route, which may climb mountains, cross rivers, and run under fields and meadows. Men with tractors and bulldozers clear the path overland. Divers clear the ocean floor, if necessary. Trench-digging machines shovel out the earth in which the pipeline will be laid.

Much pipe is now transported to the scene in trucks. The pipes are of high-duty

steel and may be about one meter or more in diameter. They are handled by caterpillar tractors, called "cats." These are provided with movable spars, or beams, known as "side-booms," which hoist and lower the pipes. First, the pipe lengths are laid end to end by the side-booms. Welders now appear on the scene and weld the pipes together, making the joints perfectly tight. As the welders move along, the pipes become a pipeline. Inspectors follow the welders, checking each pipe joint for tightness.

The pipe is now cleaned inside and out. On the outside, it is scrubbed and then wrapped by a machine in layers of special paper that has been coated with hot tar or various other substances. The wrapping protects the pipe from moisture in the ground and prevents the formation of rust. The inside of the pipeline is scrubbed clean by a machine called a pig, which has brushes attached to it. The pig is blown through the pipeline by compressed gas. It twists along through the pipe, making a loud scraping noise as it goes. When the pipeline has been cleaned, wrapped, and tested, it is carefully laid in the open trench by the side-boom "cats," and there it is completely buried. The pipe is now ready to transmit natural gas from field to consumer. A single efficient construction crew can, on the average, lay down as much as one and one-half kilometers of pipeline on land during a normal working day.

Submarine pipelines are being set in place in increasing numbers. For example, a 90-kilometer offshore gathering and transmitting pipeline system extends from offshore to the mainland in southwestern Louisiana. This extensive pipeline system taps some of the largest known submerged natural-gas reserves in the Gulf of Mexico.

COMPRESSOR STATIONS

Natural gas rushes out of a "Christmas tree" because of the pressure of the gas in the well. This pressure pushes the gas along the pipeline at an initial speed estimated at from 95 to 115 kilometers per hour. As the gas moves along, it "rubs" against the walls of the pipe. The friction caused by this "rubbing" gradually causes the gas to slow down. As a result gas pressure in the pipe drops.

To get it moving rapidly again, a compressor station is needed. In this, pumps called *compressors* boost the falling pressure of the gas by compressing it. As the gas is compressed, it becomes hot. It must then be cooled with water in a cooling tower before it is sent back to the pipeline, to be sent to the next compressor station or regulator station. Since natural gas burns easily, precautions must be taken here to prevent explosions.

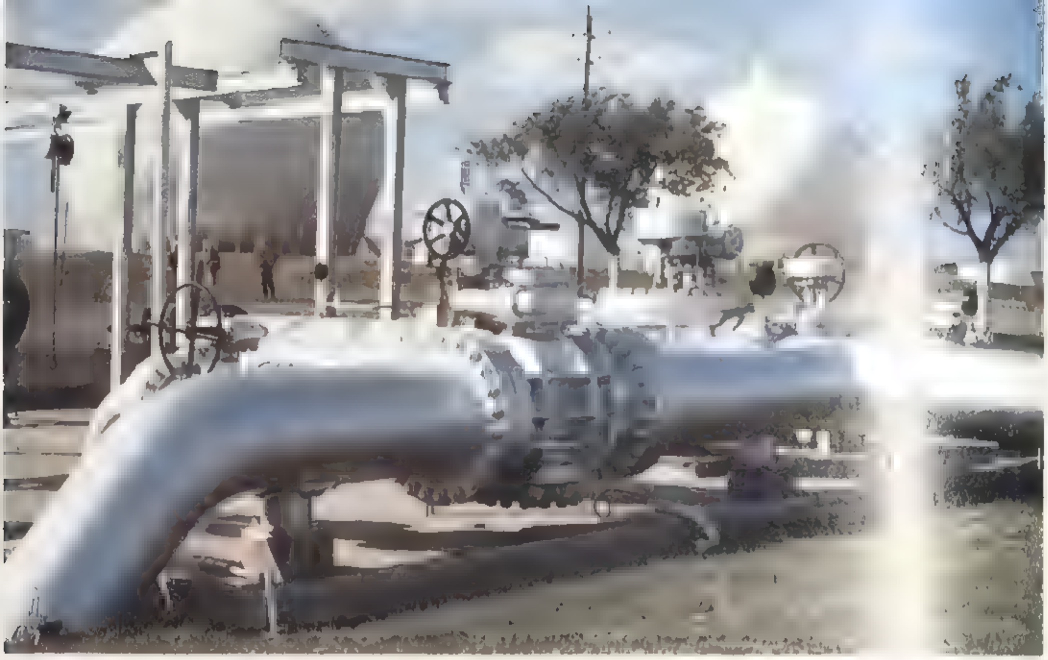
The operation of compressor stations and other pipeline units has become increasingly automatic. A remote-control gas pipeline is now operating in Louisiana, Mississippi, Tennessee, and Kentucky. One person at a centralized transmission-control console in Nashville, Tennessee, can regulate the flow of gas through a far-flung pipeline system. This includes nearly 1,400 kilometers of main line, and five remote-controlled compressor stations situated about 300 kilometers apart.

GAS STORAGE

The need for gas in a given community changes from hour to hour during the day. For example, a great deal of gas is used while people are preparing meals. After meals have been cooked, less of the fuel is needed for a time. The gas requirement also

New pipelines are being built across inhospitable Siberia to reach huge gas fields there.

Stepon Gubsky/Tass from Sovfoto



E Iefsen/FPG

Natural gas storage tanks loom behind part of the line supplying them

changes from week to week and from summer to winter, since many people use gas for heating.

Gas companies must have enough gas on hand to meet the peak demand. To do so, they usually store up the fuel while the need is low and hold it ready for the times when a great deal is needed. Sometimes the gas is pushed back into the ground—a method called underground storage. This is considerably less expensive than tank storage or any other aboveground methods.

There may be an old gas or oil field, with no more gas or oil in it, near the community. A compressor station is built in the vicinity. The station takes gas from the pipeline and then "stuffs" it into the porous rock layer below. When that gas is needed, it is released again into the pipeline. If no old gas field is available for storage, geologists may locate a layer of porous rock that has the right sort of dense rock above and below it to trap and hold gas.

Sometimes, natural gas is stored in the pipeline itself. If the pressure is raised suitably by means of pumps, a very large amount of gas can be kept in reserve in this way, since the steel pipe is strong enough so that it can withstand very high pressures. This storage method is called pipeline storage, or "line pack."

DISTRIBUTION OF GAS

At last the gas pipeline reaches your community. The pressure of the gas must be lowered before the fuel can be used in such appliances as gas ranges, furnaces, and water heaters. The flow of gas must be controlled, in order to meet the changing needs of the community. The gas flow must also be measured so that the gas company can tell how much fuel is being used by its consumers and how much to charge them for it.

All this is done at the regulator station. Here there are valves that turn the gas on and off and others that regulate the pressure. There are instruments that give the temperature and pressure of the gas and tell how much of it is passing through to the community. Many of these valves and instruments are automatic. For example, in the morning, when ovens are being lighted all over the community and pots and kettles are being put on gas ranges, valves and instruments in the regulator station let more gas through automatically. The people in charge have only to watch the operation of these devices to see that all is working well.

Many communities use only natural gas, transmitted through pipelines from the wells and controlled by means of compressor and regulator stations. In some places, the natural gas is mixed with manufactured

American Gas Assn

Storage tanks take shape at a new liquified natural gas import terminal in Louisiana.

gas in carefully regulated amounts in a place called the mixing house.

MANUFACTURED GAS

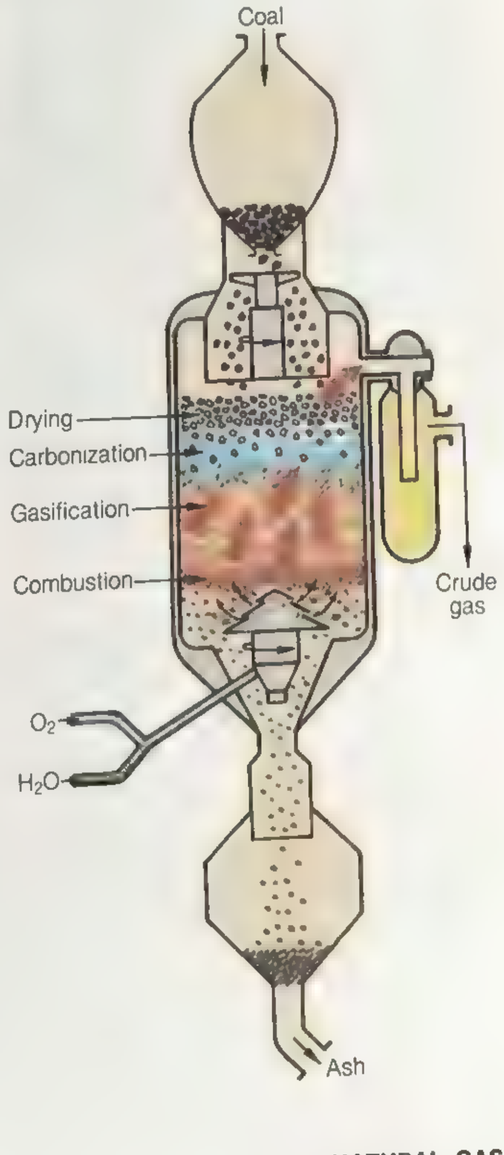
Manufactured gas used to be made from coal or coke. Virtually all of it, in the United States, is now derived from oil. It accounts for only a small percentage of all the gas sold by the industry. It is used principally as a stand-by gas for use during peak-load periods in areas served by natural gas. Comparatively few companies now market straight manufactured gas or mix it with natural gas. This may change, however, because of expected future shortages of natural gas.

MANY USES

Gas—natural, manufactured, or a mixture of the two—is used in the homes of a community for cooking, heating water, central heating, incinerators, and laundering. It also is used in certain types of refrigerators and air conditioners.

The gas industry has spent much money in research to determine how to make gas appliances more effective and economical. There have been many new developments. There are streamlined built-in gas ranges with burners no larger than a nickel. Tiny pilot lights, called "mini-pilots," give

The manufacture of gas from coal is illustrated below. More gas may be made this way as future shortages threaten supplies.



Alpha

A pipeline being laid in the Netherlands will carry gas from the rich Groningen fields

off less heat than the light bulb set in back of the gas range. Top-burner heat control makes every pot, pan, and skillet a completely automatic appliance. One of the most exciting developments is the "Multimatic Wall." This is an all-gas kitchen-appliance center. It combines cooking, laundering, refrigeration, house-heating, and water-heating in one compact unit.

Stores, restaurants, laundries, and hospitals are important gas customers. Restaurants favor gas for cooking. In fact, more than 95 per cent of the meals served daily in public dining rooms in the United States are cooked by this fuel. Laundries, launderettes, and drycleaning establishments also use great quantities of gas. In hospitals, gas heats water which sterilizes scalpels, tweezers, hypodermic needles, clamps, and other instruments that must be germfree.

Gas also plays a vital part in industry. It is employed in the processing of bricks, glass, and cement and of steel and other metals. It is used to bake enamel on prefabricated houses. It serves in the preparation of chemicals and the manufacture of paint and varnish. Food in canneries is cooked with gas. The textile industry uses vast quantities of gas. Gas heat plays an important part in bleaching, dyeing, and printing. Gas burners singe off the "stubble" that appears on such textiles as corduroy, cotton sheeting, and broadcloth after they are woven.

Gas also serves on the farm. Freshly mowed hay and alfalfa are processed in gas-fired devices to provide food for livestock in winter. Gas heats the sterilizers that disinfect hatchery equipment and the brooders in which tiny chicks are kept warm.

Natural gas is not only a fuel, but an ingredient of many industrial products. From this gas are derived carbon black, used in the processing of natural rubber, and butadiene, from which certain kinds of synthetic rubber are produced. The gas also yields potash used in fertilizers and explosives and such man-made fabrics as nylon, Dacron, Acrilan, and Orlon.

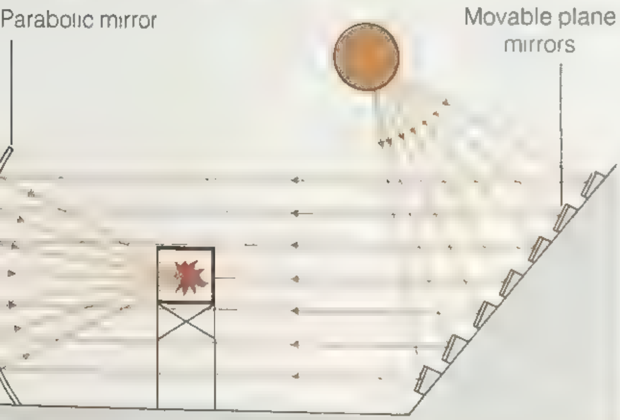
Opposite: Offshore gas wells promise abundant supplies

American Gas Assn.

SOLAR POWER

The world needs a source of power that is clean, inexhaustible, predictable, readily available, and free to all those that have the equipment to use it. We already have such a power source—the sun. The fossil fuels upon which we rely are ultimately derived from the sun's radiant energy, which is used by plants. It would be more efficient for us to use the sun's energy in a more direct manner, rather than to depend on plants to convert the energy into a usable form such as coal, oil, and gas.

DIAGRAM OF A SOLAR FURNACE



The idea of using the s[illegible] energy directly is not new. It is said t[illegible]e ancient Greek philosopher Archim[illegible] used the energy of the sun's rays to s[illegible] to an invading fleet. He intensified [illegible]eat by using mirrors. In France, seve[illegible]periments with solar-powered engine[illegible]re carried out during the nineteenth c[illegible]. Among these experiments was a o[illegible]rsepower solar steam engine, invente[illegible] Augustin Mouchot in 1866, and a [illegible] printing press, demonstrated in Paris [illegible]82.

Until recently, solar-po[illegible] engines were thought of as a scient[illegible]uriosity. They were, and, for the mos[illegible] still are, not very economical. Howe[illegible]ince the 1970s, when the depressing [illegible] of energy resources was revealed, s[illegible]ower has received growing attention [illegible] possible fossil-fuel alternative.

A solar power plant is now opera[illegible] the Pyrenees, near Odeille, France. A sy[illegible] movable mirrors reflects the sun's rays to a [illegible] parabolic mirror that in turn concentrates [illegible]flects the rays to a central point, providing hig[illegible]peratures for industrial use. The central poi[illegible] also convert the heat energy to electricity

[illegible] to Researchers

TO GENERATE ELECTRICITY

The sun is the most powerful source of energy for mankind. The energy that actually reaches the earth is about 4,000,000,000,000,000 kilowatt-hours per day. This immense number is 500,000 times the total U.S. electrical generating capacity.

Among the ways by which the sun's energy can be converted to electical energy are: photovoltaic cells, or solar batteries; windmills; and solar collectors.

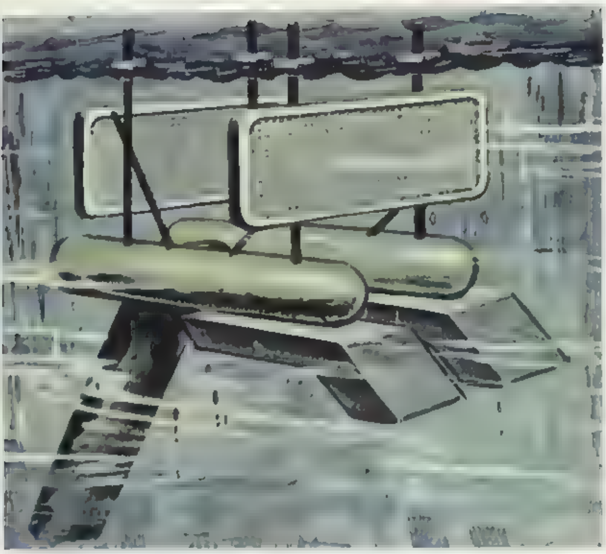
PHOTOVOLTAIC CELLS

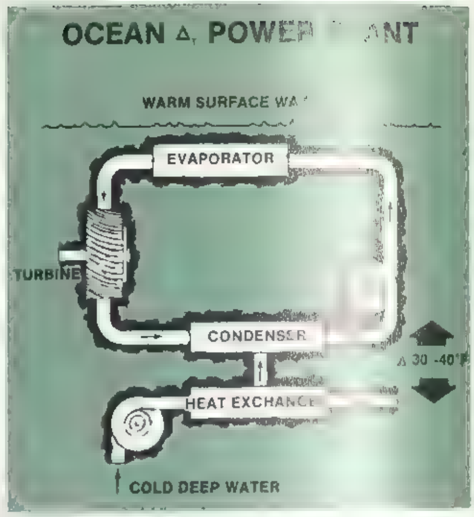
Photovoltaic cells are constructed so that sunlight shining on them is converted to electric energy. The energy output from each cell is small and many cells must be used to generate a reasonable electric current. The overall efficiency of these cells is fairly low—about 18 per cent of the incident solar radiation is converted into electricity. With technological improvements, the maximum efficiency should be about 27 per cent. In contrast, the efficiency of burning fossil fuels ranges from 30 to 40 per cent. Photovoltaic cells, however, are clean sources of power.

Other methods for tapping the sun's vast energy supply involve less direct means than a direct conversion of solar radiation into electric power.

SOLAR REFLECTORS

One method involves the use of solar reflectors. These are essentially mirrors that concentrate and reflect the sun's rays toward a central point. This point is a central receiving tower. The tower is capable of converting heat derived from the sun's rays into electricity. A 500-megawatt power plant requires about 2.5 square kilometers of mirrored surface and a tower about 450 meters tall. At the present time, France is operating large solar mirrors high in the Pyrenees. These are being used to generate high temperatures for industrial use. Means for obtaining electric energy from these set-ups are also available.



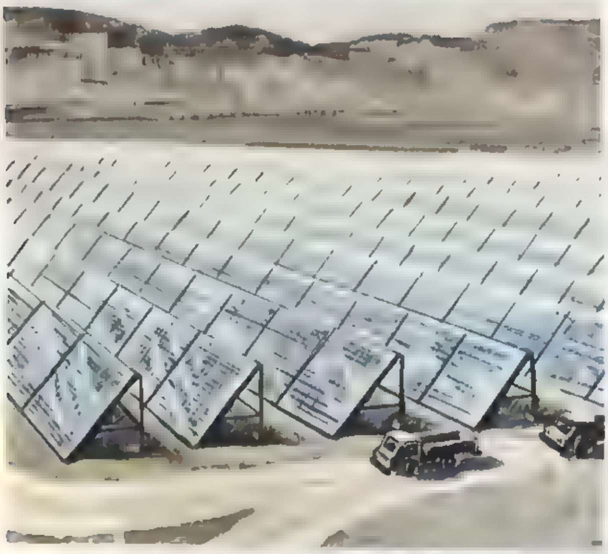


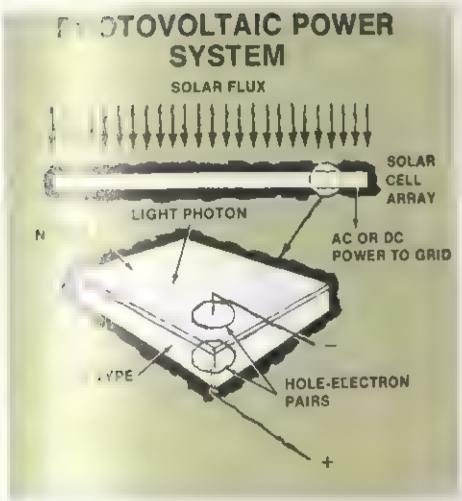
OCEAN POWER PLANT

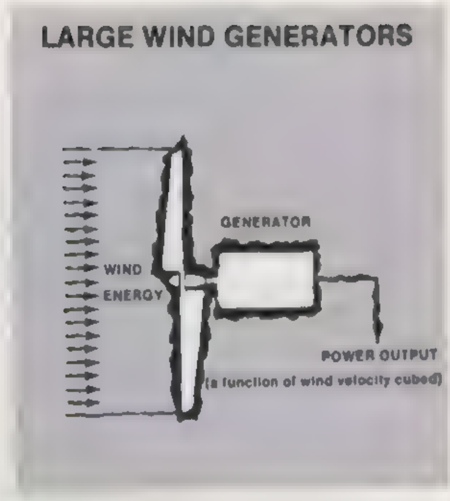
WORKING PRINCIPLE—The oceans' warm surface waters store a huge untapped reserve of the sun's thermal energy below which, at depths of more than 300 meters, lies a nearly infinite heat sink—a stable layer of much colder water. This temperature difference, or gradient, can be used indirectly by means of a heat engine to produce electricity. Rankine-cycle heat engine shown here could, when operating on a temperature difference of about 15 to 20° Celsius, achieve a theoretical maximum conversion of heat into useful work of about 5%. An overall practical efficiency of 2% is a reasonable estimate. Main requirements: an ocean thermal gradient (OTG) of 15 to 25° Celsius, such as is found in tropical and near-tropical waters and in warm ocean currents. This is the only ground-based application of solar energy that does *not* require energy storage.

POTENTIAL—An estimated 182,000,000-000,000 kilowatt hours of electricity could be generated with an array of OTG plants along the length and breadth of the Gulf Stream. This would be enough to meet the total U.S. energy demand projected for the year 2000, with less than 0.18°Celsius drop in Gulf Stream.

TECHNOLOGY GAP—Development of efficient, low-cost heat exchangers, compatible with the seawater environment, is the key to making this concept work at a competitive price.







PHOTOVOLTAIC POWER SYSTEM

WORKING PRINCIPLE—This concept of converting solar energy to electricity is based on the photovoltaic effect in solid-state devices (solar cells) laid out in huge arrays on the earth's surface. The theoretical limit efficiency for the conversion process is about 25% for a single device operating at room temperature. At present, the two leading solid-state materials for large-scale power generation are silicon and cadmium-sulfide. The United States currently produces about 90 metric tons of single-crystal silicon per year, but about 2 million metric tons would be needed to match present U.S. power needs. Roughly 1% of the total U.S. land area, or 90,000 square kilometers would be needed for this total energy system. Main requirements: large land area, maximum solar insolation.

POTENTIAL—A total area of 160 × 160 kilometers of the U.S. southwestern desert could supply total estimated U.S. electricity needs in the year 2000.

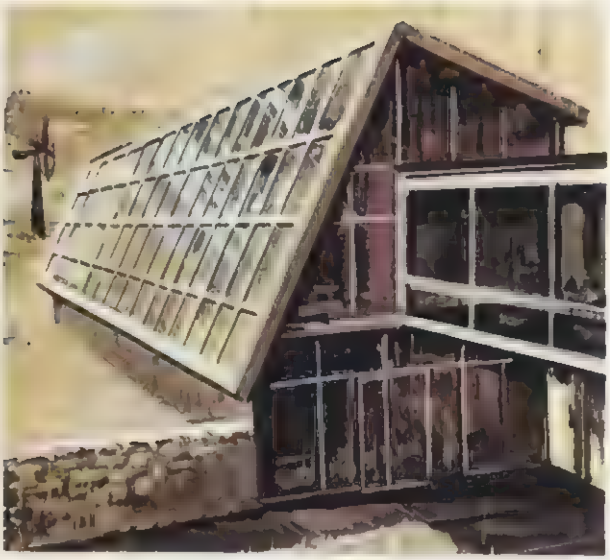
TECHNOLOGY GAP—Reducing cost and increasing life of solar arrays in the earth environment are the key to making the photovoltaic system competitive with commercial sources. The concept also requires lower-cost, longer-life energy storage devices

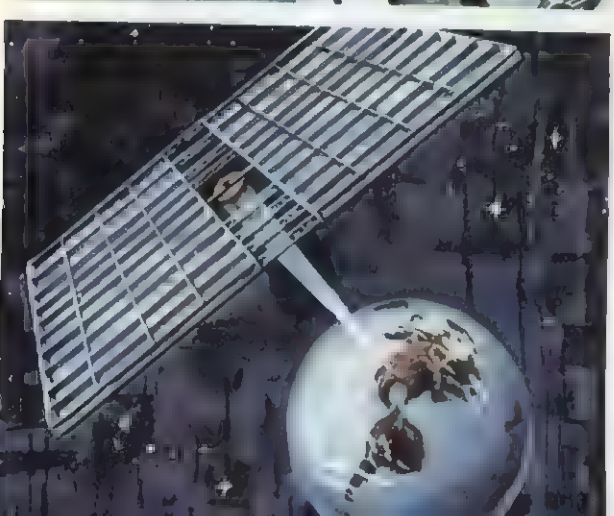
LARGE WIND GENERATORS

WORKING PRINCIPLE—As our atmosphere is alternately heated and cooled by earth's day/night cycle, winds storing the sun's energy as momentum move over the surface of the globe. Momentum-interchange devices (wind turbines) driving alternating current generators can extract this energy and convert it to electricity. In the United States, huge 60-meter diameter wind generators erected in selected coastal areas or on the Great Plains could operate with the strong, steady winds in these areas to supply electricity for large areas of population. The electric output of such generators might be fed directly into a local or national grid, used for pump storage in a hydroelectric system, or for water electrolysis to produce hydrogen as a fuel. Main requirements: steady, high-average-speed winds

POTENTIAL— Supply 50% of total U.S. electricity needs in 2000

TECHNOLOGY GAP—While no technology breakthroughs are needed, emphasis must be directed toward developing system designs that produce energy at competitive prices. Also need efficient storage devices for large-scale applications.





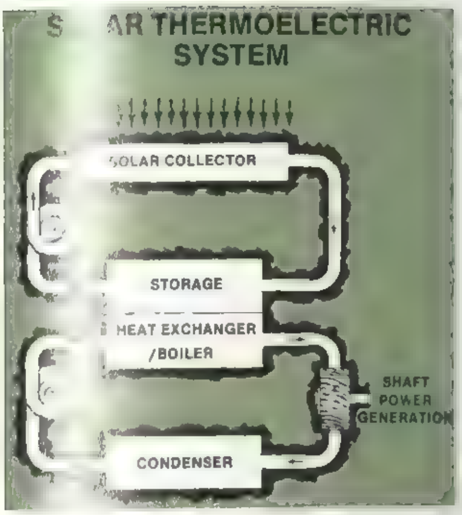
SOLAR ENERGY FOR BUILDINGS

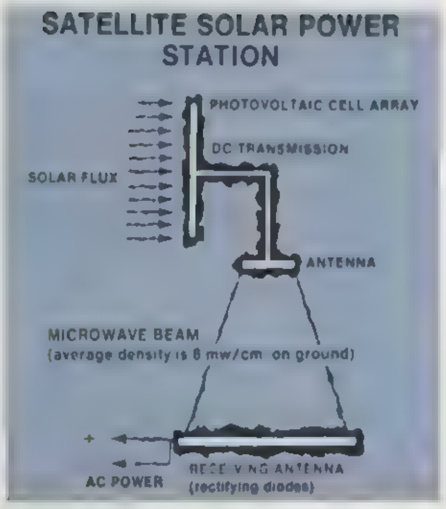
WORKING PRINCIPLE – Solar energy, in this concept, would be used (1) to heat and cool buildings by means of a solar collector and (2) to provide electric power by means of a small wind generator or "windmill." In the solar collector, thermal radiation is transmitted by glass covers and absorbed by a blackened metal sheet. Temperature of fluid circulated in collector can reach 40 to 90° Celsius. System includes a heat storage tank, an auxiliary heater, and an air conditioner

An 8-meter-diameter wind generator would meet a typical house's average power demand of about 2-3 kilowatts

POTENTIAL – Provide 50 to 75% of future buildings thermal energy needs

TECHNOLOGY GAP – Main need is for well-engineered, economical solar collectors. Also need more efficient heat and electric storage devices and air conditioners operated with lower temperature inputs. System preferably would include its own storage and peaking capability to span variations in available wind energy and consumer home demand.





SOLAR THERMOELECTRIC SYSTEM

WORKING PRINCIPLE—Thermal conversion systems consist of solar collectors, such as the trough-type shown above, and thermal storage devices delivering heat to a turbine power plant. With high-temperature selective solar-absorber coatings developed for the space program, temperatures needed to run standard steam turbogenerators can be achieved with relatively low solar concentration. Conversion efficiencies (direct solar energy to electric energy) of 20–30% are estimated. In the southwestern United States, about 25 square kilometers are needed for a 1,000-megawatt power plant operated at an average of 70% capacity. Main requirements: large land areas, maximum solar insolation.

POTENTIAL—A roughly 100 × 100 kilometer area of the U.S. southwestern desert would provide total estimated electric needs in the year 2000

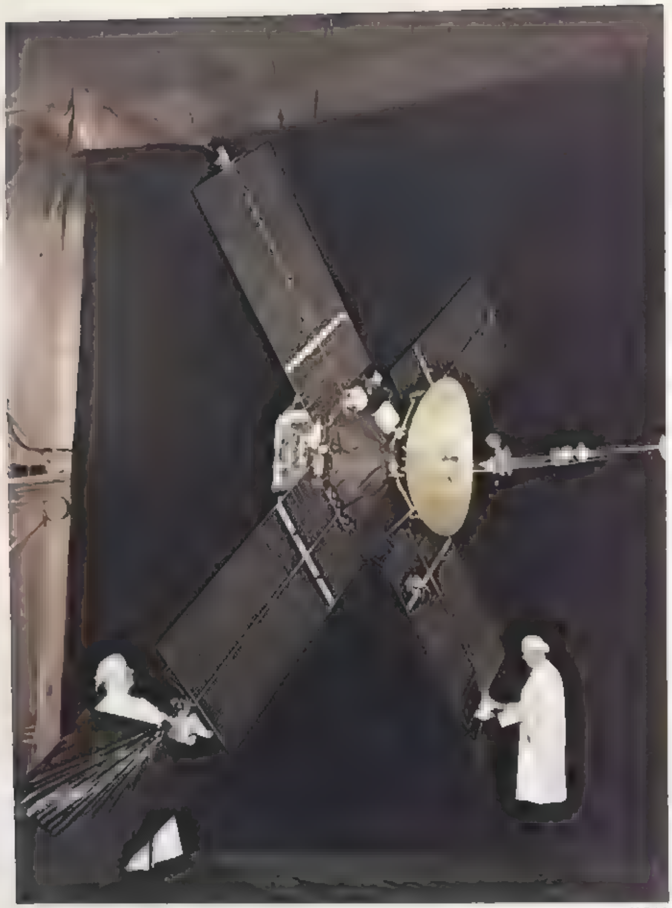
TECHNOLOGY GAP—Key problem is to find an economical design for long-life operation with a minimum of maintenance. Such optical components as the concentrator and absorber surfaces must perform for many years while exposed to the elements. Efficient heat transfer and storage devices must be developed

SATELLITE SOLAR POWER STATION

WORKING PRINCIPLE—Outer space offers the one location with constant access to the sun's energy. A Satellite Solar Power Station (SSPS), positioned in a synchronous orbit 30,000 kilometers above the earth's equator, would receive solar energy for 24 hours a day except for short periods near the equinoxes It would receive 6 times the solar energy available to an equivalent array on earth Assembled in space, a typical SSPS might be composed of light-weight solar cells forming a huge solar collector about 10 kilometers long by 4 kilometers wide The electricity produced would be fed to a microwave antenna, which directs a beam to a receiving station on earth where the microwave energy can be safely converted back to electricity Efficiency of microwave energy conversion on earth is estimated at 90% SSPS designs currently being considered would provide 5,000 megawatts to the power grid

POTENTIAL—One hundred SSPS's could supply the estimated total U.S. electric power demand in 2000

TECHNOLOGY GAP—Key to making this concept practical is development of a light-weight, mass-produced, low-cost, thermal-insensitive solar cell and efficient high-volume space transportation systems



USIS

Solar panels are installed on spacecraft that will fly extended missions. Electric energy will be produced by the cells, rather than by convention[illegible]

WINDMILLS

Another method of power generation involves the use of windmills. Wind is caused by the unequal heating of the earth's atmosphere. The force of the wind is powerful enough to turn the blades of a windmill, which in turn drives a turbine. The turbine generates electricity.

SOLAR COLLECTORS

Solar collectors are objects that absorb much of the heat from the sun's rays. Solar collectors are being investigated for power generation.

One method involves using the largest solar collector on earth—the surface of the ocean. The surface waters of the ocean absorb a great deal of solar energy. The sun's incident rays are converted to heat that warms the surface layer of ocean water. The temperature of surface waters in tropical regions is about 30° Celsius. However, about 600 meters below the surface, the temperature is about −15° Celsius. It is possible to design and operate a system that uses this thermal gradient, or difference in temperatures, to run a turbine, producing electric current.

TO HEAT AND COOL

As far as the immediate future of solar power is concerned, the most promising scheme for using solar energy is solar heating and cooling of buildings.

COLLECTING HEAT

The most common type of collector for space heating is a flat plate designed to absorb both radiation falling directly on it and radiation scattered by the atmosphere.

Collectors are usually panels of aluminum, copper, or steel. The panels are usually painted black. The black coloring inhibits reflection and encourages absorption. Insulation is placed behind the collector to prevent heat loss.

The collector is covered with glass or

plastic. This layer allows short-wave radiation (light) to enter the collector. As this radiation passes through the glass or plastic, it is transformed from short-wave to long-wave (heat) radiation. Long-wave radiation cannot pass through the glass or plastic back into the atmosphere. Therefore, heat is trapped within the collector. If this account sounds familiar to you, it is because the principle is the well-known "greenhouse effect."

Collectors are usually mounted at an angle to maximize the amount of radiation falling on them. Most collectors are mounted at a slope that is perpendicular to the sun's rays.

TRANSFER AGENT

Air or water is circulated through the collector, and becomes heated. As it leaves the collector and travels through the heating ducts of a house, it warms the air inside the house, or brings hot water to sinks, tubs, and appliances. Air systems have the advantage of avoiding corroding problems, but air is a less efficient medium for heat transfer. Water is therefore more frequently used.

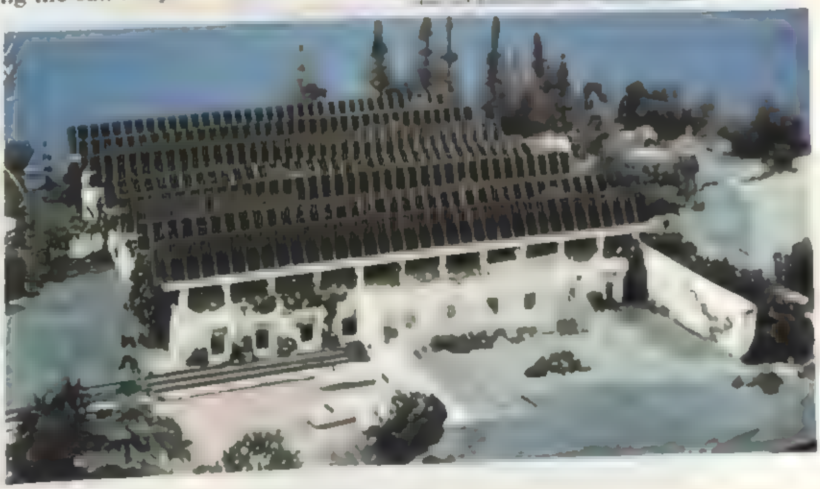
Air-conditioning systems based on solar energy have also been designed. They are dependent upon the absorption of coolant in a refrigeration system.

STORAGE

One problem with using the sun's rays for heating is storage. Heat must be stored for nighttime use and for use during cloudy days. Heat can be stored in a large insulated tank of water in the basement. Variations on this theme have been tried. Another system uses about 40 metric tons of rock to store heat.

There are some disadvantages to the use of solar power for heating and cooling. The major one is that a back-up system is needed for a long stretch of cloudy, cold days.

Photo of a solar-heated suburban house with solar collectors on the roof of the house



A new building at the New York Botanical Garden's Cary Arboretum in Milbrook, New York, will be solar heated. The collectors face south and the back of each collector row is reflective, thus increasing the solar radiation on the row of collectors positioned behind

GEOTHERMAL ENERGY

The search for new sources of energy is on. People have become increasingly aware that the supply of oil, natural gas, and even coal is limited and going fast. At the same time modern technology and a rising standard of living around the world are increasing the demand for readily available and economical sources of energy. Nuclear power, many believe, will provide the answer. But at the same time, other—more exotic—sources of energy are being studied. One of these is geothermal energy.

WHAT IS IT?

Geothermal energy is the heat deep inside the earth. This internal energy is thought to be the result of the natural decay of radioactive material inside the earth. It is virtually inexhaustible—a vast potential source of power. But can it be tapped economically and in large enough quantities?

Theoretically, such energy could be obtained at any point on earth by drilling deeply enough and providing some kind of arrangement for extracting the heat. But in most parts of the world the hot interior mass is too deep to reach with existing drilling technology. In some areas, however, such as many spots in the western United States, in parts of New Zealand, and in Italy, large heat sources are close enough to the surface to reach, but their exact locations are not known in all cases.

Geysers, or hot springs, such as the one shown below, can be tapped to provide power. Unfortunately, however, there are only a few areas in which such springs occur near the surface.

Ginette Laborde—Charenton Paris

There are three basic sources of geothermal heat: natural steam, hot water, and hot dry rock. So far, geothermal steam has been used mainly to generate electricity. Hot water—with and without steam—has been employed largely for heating purposes in a very few locations, but its application to power generation is now being seriously proposed. Dry hot rock, which is the largest heat resource, has not yet been tapped, but several new methods for using it are being considered.

STEAM TO ELECTRICITY

Historically, the commercial application of geothermal energy for generating electricity dates back to 1904 in Italy. Today, electrical power is being produced from geothermal sources in New Zealand, Japan, the United States, Iceland, Italy, and the Soviet Union. In the United States, the major geothermal power plants are located at a natural steam field in California known as The Geysers. There, steam is collected from a number of wells, filtered, and passed through turbines that drive electric generators.

Because of the lower pressures and temperatures of the steam at The Geysers plants, the fraction of the available heat that is converted to electrical energy is less than that achieved by conventional fossil fuel steam electric power plants. However, this type of geothermal installation costs less to build than a conventional steam plant of the same capacity. Furthermore, the time required to put a geothermal plant into operation is much less than that for fossil or nuclear plants.

The total electrical capacity at The Geysers is now about 400 megawatts. A program is under way to add about 100 megawatts per year for several years, at which time the field will be able to furnish as much power as that used now by the city of San Francisco. The total potential geothermal capacity at this location is estimated to be in the range of 1,000 to 4,000 megawatts, a sufficient capacity to serve one-half the present needs of the greater San Francisco metropolitan area. A large geothermal power plant in Larderello, Italy, the first ever to be constructed, generates some 300 megawatts; a plant at Wairakei, New Zealand, some 200 megawatts.

The use of natural steam is fully developed commercially, and the overall cost of the power is less than that generated by fossil or nuclear plants. The technology is limited in its application, however, because additional dry steam fields are not known and are not believed likely to exist.

HOT WATER TO ELECTRICITY

The geothermal wells in The Geysers region of California and at Larderello in Italy produce steam without hot water. It is more common for geothermal wells to yield a mixture of steam and hot water. The steam is produced because a portion of the hot water spontaneously boils as the pressure is reduced when the water comes up to the surface.

The combination of steam and hot water is less useful then dry steam. Much greater quantities of fluid must be produced by the well for a given plant generating capacity, and more water must, therefore, be disposed of, usually by reinjection into the earth. Also, since generally only the steam is used to generate power, as much as half of the available heat may be discarded with the water. The overall efficiency in using the original thermal energy is, therefore, correspondingly less than for dry steam.

There are many places where hot water wells without steam are located, but only limited use has been made of these resources. In one proposed method of harnessing this energy, known as the "vapor-turbine cycle," the hot water is passed under pressure through a heat exchanger. The hot water causes a sealed-in secondary liquid with a lower boiling point—such as isobutane or freon—to vaporize.

This vapor expands through a turbine, which drives an electric generator. It is then condensed to a liquid and returned to the heat exchanger to start the cycle all over again. The original geothermal well water, which does not boil because it is kept under pressure, is returned to the ground.

The most important feature of the vapor-turbine concept is that it may permit the generation of electricity from geothermal waters at temperatures that would not be practical or efficient for steam turbines. An installation of this type is in operation in the Soviet Union, and several small prototype units are now planned for the western coast of the United States.

Another promising idea, formulated at the U.S. Energy Research and Development Administration's Lawrence Livermore Laboratory, is intended particularly for application to the hot waters of the Salton Sea area of Southern California, which contain heavy concentrations of minerals.

The proposed system, which is called the "total flow" concept, is designed to convert a portion of the thermal energy of the pressurized steam and hot-water mixture directly into kinetic energy. This would be done through the use of a converging-diverging nozzle, roughly comparable to a jet engine. The resulting high-velocity output would be used to drive a modified hydraulic impulse turbine and, in turn, an electric generator. Theoretically, this system would be expected to produce 60 per cent more power than other methods designed to extract energy from geothermal waters at the temperatures and pressures involved.

HOT WATER FOR HEATING

Hot water from underground sources has also been used extensively for many years in Iceland, not for generating electricity, but for heating purposes. Today more than 90 per cent of the homes in Iceland's

city of Reykjavik are heated by hot water. The water is piped through an elaborate network from neary geothermal wells.

Heating of homes with geothermal hot water is also being developed on a large scale in Japan, New Zealand, the Soviet Union, and Hungary. In the United States, house heating from hot water wells has been used in Boise, Idaho, and Klamath Falls, Oregon, for many years.

In New Zealand, hot geothermal water has been used for industrial process heating. In Japan, other applications have included soil heating and experimental fish-farming projects. In the Soviet Union and New Zealand, geothermal hot water has been employed in air conditioning and refrigeration systems.

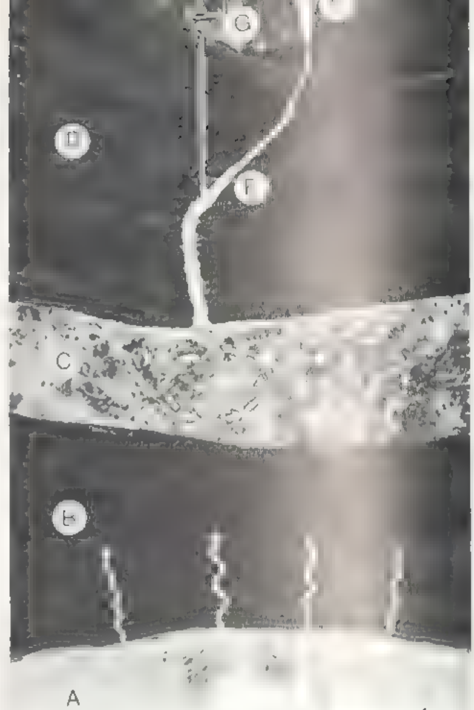
DRY HOT ROCK

Although the principal practical uses of geothermal energy have been associated with naturally occurring steam or a mixture of steam and hot water, evidence indicates that by far the largest potential geothermal energy resource is dry hot rock.

One promising method of extracting heat from deposits of dry rock employs a technique used in petroleum recovery. In this scheme, high-pressure water would be used to create a large vertical crack in hot rock, such as granite, which overlays an area of high heat flow from the earth's interior. Pressurized water would then be forced through the crack to extract the heat.

There are uncertainties in this method. For example, it is not known whether the various hot rock formations would be sufficiently impermeable to keep the pressurized water from leaking away. It is believed that the hot rock might contract as it cools so that the initial cracks would be extended to make new hot rock available for extraction of additional heat. Considerable experimental work is needed in order to learn how a rock such as granite will behave under various conditions of high temperature and pressure.

Another method of using these sources of dry heat is to create large artificial cracks by means of explosives, and then to circulate water from the surface through the extended areas of the cracks in order to extract the heat. This technique requires extensive investigation because there are several major problems involved, including the effect of blast waves on surface facilities, the economics of creating sufficient fresh rock surface to extract in useful quantities, and how fast the rock will conduct heat to the cracks from where it is being withdrawn.



...s & Electric Co

In a geothermal field, heat from the cooling of the earth's molten mass (A) is conducted through solid rock (B) and boils water found in porous rock (C). Steam escapes from solid rock through fissures (E), forming a geyser, or hot spring (F). Wells (G) tap the fissures. However, less tha[illegible] per cent of the heat stored in geothermal fields c[illegible] be extracted.

LOCATING GEOTHERMAL RESOURCES

Sources of geothermal energy must obviously be located and explored before they can be used. One of the most important first steps is to outline broad regions where the outward flow of heat near the earth's surface is significantly greater than average. For various reasons, temperatures at the surface can be misleading and it is, therefore, more reliable to make measurements at depths of 20 to 90 meters.

Geothermal exploration has in the past been largely confined to locations in the vicinity of hot springs and has used methods developed by the petroleum industry. Such techniques are not necessarily well suited to discover and evaluate possible new geothermal fields, and new specialized methods are now being developed.

Measurements of how well rock masses at various depths conduct electricity—as well as magnetic, electromagnetic, and gravity readings—are analyzed to determine if the rock structure is such that geothermal energy is likely. Seismic methods are also used. In addition, chemical analyses of waters can give further information about the nature of related heat deposits.

It is also vital that the technology of deep drilling and drilling at high temperatures be improved. At depths of over 6,000 meters, drilling costs increase sharply. Furthermore, at temperatures approximately 200° Celsius and above, the reliability of instruments used to obtain information about conditions at the bottom of a well deteriorates rapidly. Particularly needed are higher-performance drills and drilling fluids, as well as instruments that will operate more reliably in geothermal wells.

ENVIRONMENTAL EFFECTS

From an environmental standpoint, putting geothermal energy to work has many advantages. An important one is that almost all the activities related to the production of geothermal power are in the immediate vicinity of the plant. The kind of distant support operations required for fossil or nuclear plants—such as mining, fuel processing, transportation, storage, and other handling activities—are not involved.

On the negative side, there are certain undesirable environmental effects that could extend for some distance from a geothermal plant location. For example, the proper disposal of waste water from steam or hot-water wells can become an important problem, particularly when the water has a substantial mineral content. Gaseous discharge may also be a significant factor, because of the noxious gases produced by some geothermal wells. Other difficulties, which are similar to those experienced by fossil or nuclear generating plants, include waste heat disposal and the atmospheric effect of cooling towers. In some instances, undesirable environmental impacts may be produced by seismic effects and the sinking of land surfaces that lie above reservoirs from which geothermal fluids are withdrawn. On balance, however, the environmental problems raised by the use of geothermal energy are not as serious as those connected with steam electric plants burning fossil or nuclear fuel, and can be satisfactorily handled by known technology.

PROSPECTS

Although geothermal energy is not likely to become available in large quantities in the very near future, its inherent advantages make it an important potential supplement to nuclear and fossil fuels for many purposes.

The most important characteristic of geothermal energy is its potential availability in large quantities—possibly on an inexhaustible basis—wherever it can be located, tapped, and utilized.

As a source for the generation of electricity, geothermal power stations are economically competitive with fossil and nuclear plants in the areas of construction and operation, and will produce less total environment impact than those kinds of plants.

The U.S. Department of Energy has estimated that there could be about 15,000 megawatts of geothermal power capacity in the country by the end of the century. This would represent about 1.5 percent of the country's expected total power capacity at that time. If an aggressive research and development program were pursued successfully, proponents estimate that geothermal power could provide as much as 150,000 megawatts, or 15 percent of U.S. power capacity in the year 2000.

Since the technology required for direct-heating applications is largely available, there is also good reason to be optimistic about the contributions that geothermal energy can make in this field.

NUCLEAR ENERGY

The notion that all the common materials of our everyday life are actually made up of elementary particles too small to be seen is by no means new. It was eloquently expressed by the Greek philosopher Democritus, who lived during the fifth and fourth centuries B.C. Democritus said that all matter is broken up into an infinite number of eternal, invisible particles so small that they are the smallest units that can exist. These he named *atoms*, meaning "indivisible."

However, Democritus' theory failed to persuade Aristotle. Instead, Aristotle adopted the idea of another early philosopher, Empedocles, who thought that there were four basic elements: air, earth, fire, and water. Thanks to Aristotle's overwhelming intellectual authority, this vague idea ruled for more than 2,000 years. Democritus' atomic theory found no favor until the 16th and 17th centuries—when scientists such as Galileo, Francis Bacon, Descartes, Boyle, and Newton took the view that matter is not continuous but is made up of discrete basic particles.

But it was an early 19th-century English chemist, John Dalton, who was the first to state atomic theory in approximately its present form. Dalton studied the relative weights of "ultimate particles," as he called atoms, and showed how to determine the weights of different atoms relative to one another. This opened the door for the tremendous burst of creative thinking and experimentation based on the concept of the atomic unit that marked the 19th century. It was capped by the work of Ernest Rutherford and Niels Bohr, early in the 20th century, establishing the structure of the atom more or less as we now understand it.

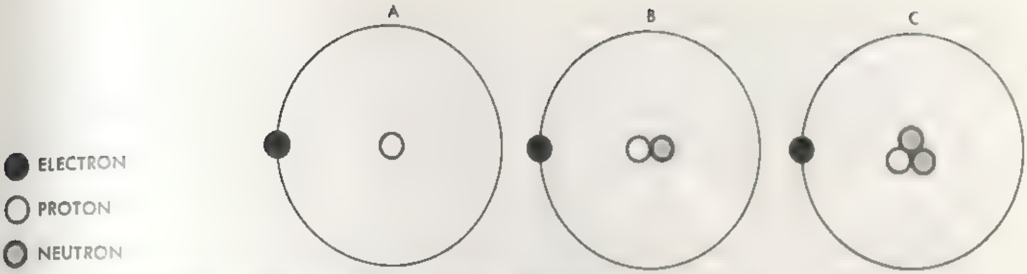
STRUCTURE OF AN ATOM

In simplest terms, the atom is much like a tiny solar system. Atoms are on the order of 10^{-8} centimeter in diameter. Each atom consists of a *nucleus* or *core*, at the center, and *electrons* spinning around it in orbits. If an atom of gold were as large as a bale of cotton, its nucleus would be no larger than a speck of black pepper at its center. The nucleus, in turn, is composed of two kinds of particles: *protons* and *neutrons*.

Unlike the sun's planets, electron orbits are not in a single plane. Two or more electrons may be in orbits having the same diameter but in planes at angles to each other. Each group of orbits of about the same diameter is called an electron *shell*.

Thus, Democritus, for all his insight and deductive power, was wrong in conceiving of atoms as indivisible, since electrons, protons, and neutrons are the building blocks of the atom. It is important to note at this point two properties of these particles: their mass (weight) and electrical charge. Protons and neutrons have about the same weight—an arbitrary "atomic weight" of 1. In everyday units, they weigh about 1.674×10^{-24} gram—that is, 0.000000000000000000000001674 gram. The electron has a mass only 1/1837 that of the proton (9.106×10^{-28} gram—that is, 0.0000000000000000000000000009106 gram). The proton has a positive electrical charge, while the neutron is uncharged, or neutral, electrically. The electron has a negative charge.

From this we can see, first, that essentially all the weight of the atom is in the nucleus. Second, the positive charge of a proton in the nucleus is balanced by the negative charge of an electron orbiting around the nucleus. In fact, the lightest and simplest atom, the common form of hydrogen, consists of only one proton making up the nucleus and one electron circling it. Because the mass of electrons is negligible compared to that of a proton or neutron, the hydrogen atom that contains only one proton and no neutrons is said to have an atomic mass of 1.



The ato… structure of three isotopes of hydrogen Shown here are *(A)* common hydrogen, H^1; *(B)* deuterium, H^2, or D; *(C)* tritium, H^3, or T. Two of these hydrogen isotopes—deuterium and tritium—are radioactive.

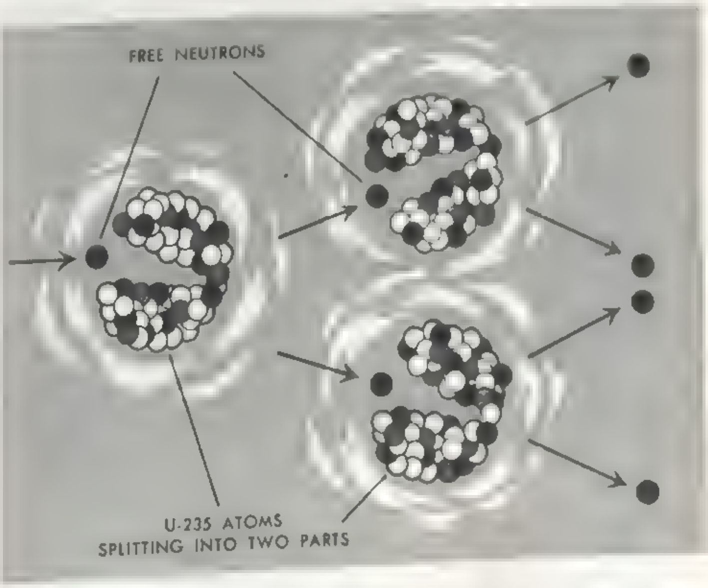
As nuclei progressively increase in size, the atomic mass goes up by 1 for each additional proton or neutron. For each additional positive proton in the nucleus, a corresponding negative electron is found circling the nucleus. Thus the commonest form of the second lightest element, helium, has a nucleus composed of two protons and two neutrons and it has two planetary electrons. Helium is said to have an *atomic number* of 2, because it has two protons. The neutrons add no charge, but do add mass to the atom. The common form of helium has an *atomic mass* of 4; it has two protons and two neutrons, each with an atomic mass of 1.

Physicists sometimes refer to the atomic number as the *Z number,* and to the atomic mass, or weight, as the *A number.* They also use a system of notation in which the A and Z numbers are attached to the chemical symbol of the element. Thus ${}_8O^{16}$ means that oxygen—chemical symbol 0—has atomic number 8 and atomic mass 16. The nearest whole number indicates the atomic mass.

There are 92 naturally occurring elements on earth, from hydrogen, ${}_1H^1$, to uranium, ${}_{92}U^{238}$. Many of them, such as gold, silver, iron, copper, and sulfur, have been known to man since before recorded history. Certain elements with atomic numbers greater than 92 have been produced synthetically within the past few decades. They are called *transuranium elements* because each has an atomic number greater than that of uranium.

Atoms can exchange electrons in their outer shell to form chemically different substances. Reactions involving electron exchanges are called *chemical reactions,* and constitute the subject of all of chemistry. Until well into the twentieth century, these were the only kind of reactions

Highly simplified diagram of a chain reaction, involving fissionable U-235 (uranium with mass number 235). A free neutron collides with a uranium atom, causing it to split into two and releasing up to three free neutrons. If neutrons released by the first fission collide with other U-235 atoms, other fissions will take place, and still more free neutrons will be released.



known. The nucleus itself was considered inviolable. The first successes in "atom-smashing"—in firing protons or electrons into the nucleus itself and studying the reactions within the nucleus—led to the atomic bomb and the harnessing of nuclear energy.

Actually many years of research preceded the actual smashing of the atom. In the late nineteenth and early twentieth centuries, French scientists—Antoine Henri Becquerel, who discovered radioactivity, and Pierre and Marie Curie, the discoverers of the radioactive elements polonium and radium—opened a new era in the study of the atom. The existence of the electron was proved by J. J. Thomson. Rutherford established the existence of the nucleus and of alpha and beta rays. Bohr adapted Rutherford's model of nuclear structure to fit the quantum theory explanation of energy change in an atom. These were a few of the principal contributions to the detailed study of atomic structure and energy.

RELEASE OF NUCLEAR ENERGY

In 1939 Otto Hahn and Fritz Strassmann in Germany discovered that the nucleus of the uranium atom could be split, or *fissioned*, approximately in half if a neutron were accelerated and fired into it. The splitting was accompanied by the release of great amounts of energy. This was a remarkable forward step toward the goal of making available to man the immense stores of energy derived from the nucleus of the atom.

At the time of their discovery, Hahn and Strassmann did not realize that they had been able to fission only a rare *isotope* of uranium—the isotope U-235, or uranium with atomic mass 235. What does the word "isotope" mean? Most elements have different forms. The atomic number—the number of protons in the nucleus and of planetary electrons—is identical in each form. But because there may be one, two, or three more or fewer neutrons in the nucleus, the element's atomic mass is different. Such different forms of the same element are called isotopes.

Very soon after Hahn and Strassmann first fissioned uranium, it was established that the isotope U-235 could be fissioned and that U-238 is nonfissionable. It was soon also determined that 99.3 per cent of the uranium found in nature consists of nonfissionable U-238 and only 0.7 is U-235.

U-235 is fissionable because when a neutron penetrates the nucleus, bringing the total number of protons and neutrons from 235 to 236, instead of another neutron being expelled as one might suppose, the new nucleus breaks, instead, into two parts. These *fission fragments* are isotopes of elements in the middle of the periodic table, ranging from selenium to lanthanum (atomic numbers 34 to 57). In addition, between one and three neutrons are released per fission. They travel at velocities of thousands of kilometers per second; hence they are called *fast neutrons*. Finally, a tremendous amount of energy—about 200,000,000 electron volts—is released in the fission of a uranium nucleus, in the form of heat.

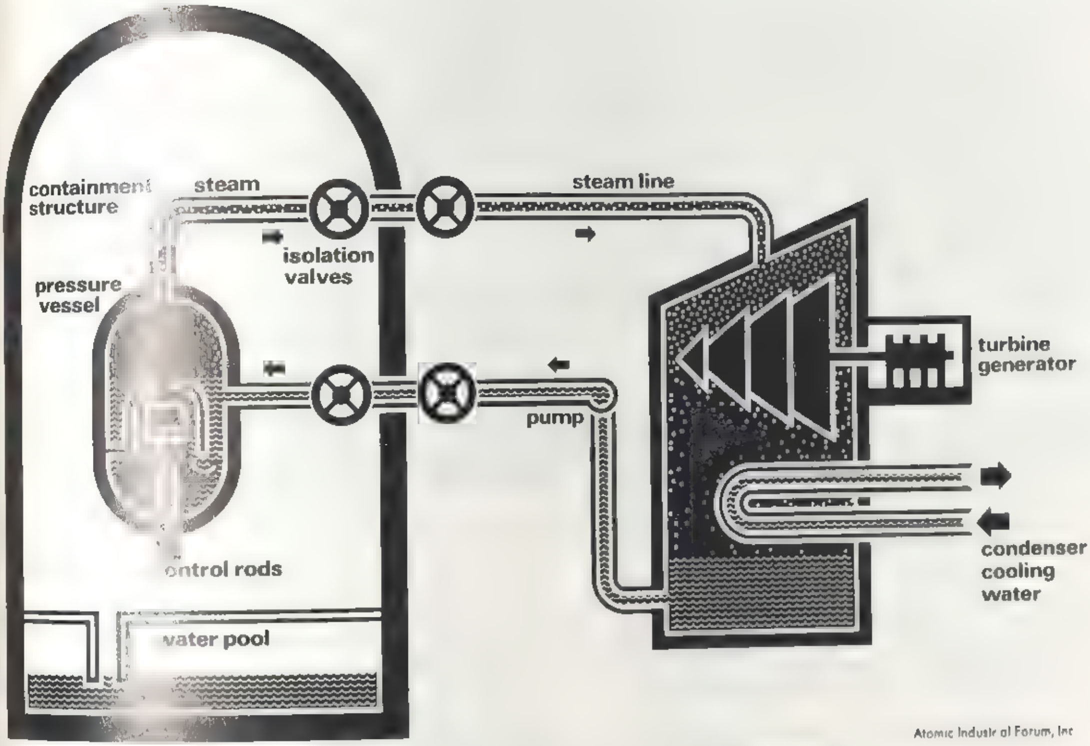
A CHAIN REACTION

If U-235 fissioned, but in so doing produced only fission fragments and energy, the phenomenon would represent only a scientific curiosity. The important fact is that neutrons are also given off at the instant of U-235 fission. It is these neutrons that make possible a *chain reaction*.

Imagine a basketball court whose floor is covered with mousetraps, each holding in its jaws a Ping-Pong ball. If a ball in a given trap is struck by another ball, the impact upon it will suffice to release it. Imagine, then, someone on the balcony throwing one Ping-Pong ball onto the court. It hits one trap, springing it, and bounces up. The two balls fall back on two others, releasing them, and now four are falling again to release four more—then 8, 16, 32, and so on. Soon the court is full of flying Ping-Pong balls.

This suggests the principle of the chain reaction. As in the case of the Ping-Pong balls, the fission process, once begun, can be *self-sustaining*. It is important that not just one, but up to three neutrons should be

Boiling water reactor (BWR)



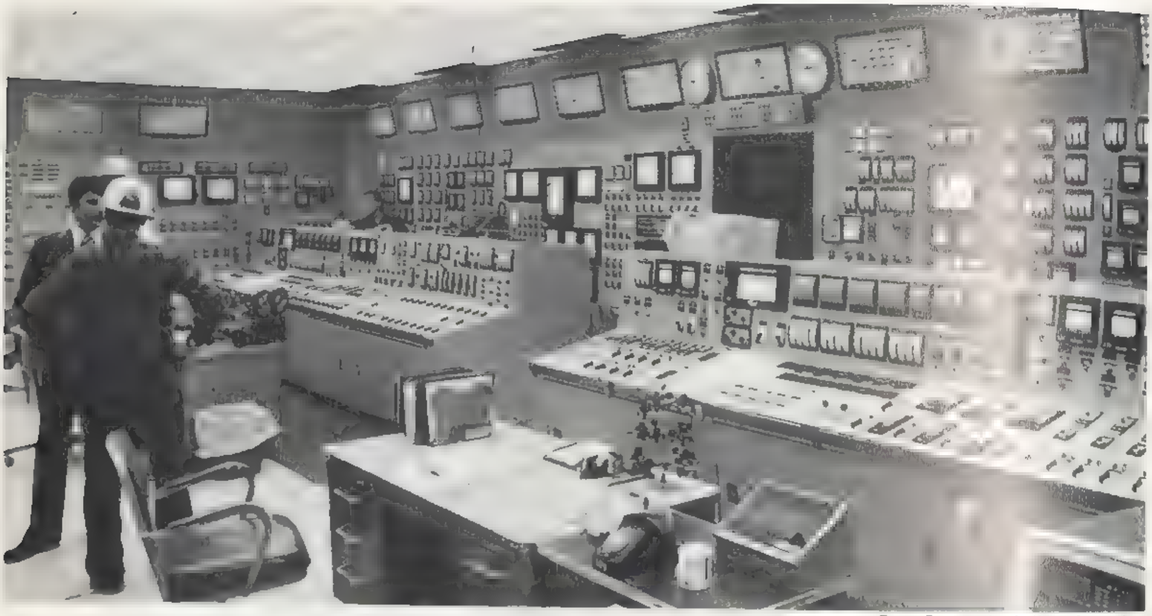
The di…am shows the pressure vessel, containment structure, and generator of a b…g water reactor. The reactor fissions nuclear fuel to heat water to steam. As in conventional fossil-fuel power plants, the steam drives a turbine, which tu…s a generator. Passing through the fuel assemblies in the pressure vessel … control rods that can be moved up or down to slow or speed the reactic…

released in each fission, because not every neutron will cause a new fission. Some will be "parasitically captured" by lodging in U-238 nuclei, which do not fission. Some will be absorbed in the structure containing the uranium. Others will escape from the uranium mass altogether without penetrating any atoms. But, statistically, enough neutrons are liberated to assure a *multiplication factor* of at least 1. This means that 100 free neutrons now present in the system will produce no fewer than 100 new free neutrons. They may produce more than 100.

To keep a chain reaction going, a certain amount of fissionable material is necessary. The mass must be large enough so that not too many free neutrons escape without producing other fissions. Such a minimum mass is called a *critical mass*. By extension of the phrase, a mass of fissionable material is said to be *critical* when a chain reaction is taking place in it. The critical mass varies with the geometric configuration of the material in which the fission is taking place and with the different materials that are subjected to fission.

THE NUCLEAR REACTOR

The controlled fission of atomic nuclei is brought about in the nuclear reactor. To put the matter as simply as possible, a reactor is a device for the gradual release of



Georg Gerster Rapho/Photo Researchers

The various components that make up a nuclear reactor must be very carefully coordinated. This is done via the control room. Note the very sophisticated automated equipment in this typical control room set-up.

nuclear energy. There are two general classes of reactor. One provides energy for generation of electric power or supplies heat for industrial purposes. Such reactors operate at high temperatures. Other reactors function to provide radiation, which is used to produce nuclear fuel or to make radioactive isotopes for use in research and medicine.

All nuclear reactors consist of a heavy, tanklike vessel that houses a *core* of nuclear fuel. Most reactors also contain a *moderator* to slow the speed of neutrons to the point at which the chain reaction can be sustained. All but very low-power reactors have a *coolant* liquid to carry away heat generated by the nuclear reaction. The speed of this reaction is regulated by a *control system*. Rigid safety precautions govern the operation of reactors, handling of radioactive by-products, and disposal of dangerous waste.

REACTOR VESSEL

The reactor vessel must be designed to withstand high pressures generated by most chain reactions, to protect people from radiation, and to resist corrosion by hot, swiftly moving coolants. Provision must also be made for loading and unloading fuel into gridlike structures supporting the core. Nearly all vessels are made of stainless steel or of carbon steel lined with stainless steel. The walls are at least 15 centimeters thick. Thick concrete blocks surround the pressure vessel to absorb neutrons and other radiation that escapes from the vessel.

Almost all U.S. power reactors use water as both moderator and coolant. The water enters the vessel at the bottom, flows upward over the fuel elements of the core, and is heated to provide steam for the generation of electricity. Control rods—containing elements, such as boron and cadmium, that absorb neutrons—are raised and lowered into the core. They regulate the power output of the reactor by controlling the speed of the chain reaction.

THE CORE

Reactor designers have a choice of three nuclear fuels: U-235, plutonium (Pu-239), and U-233. U-235 is a natural isotope

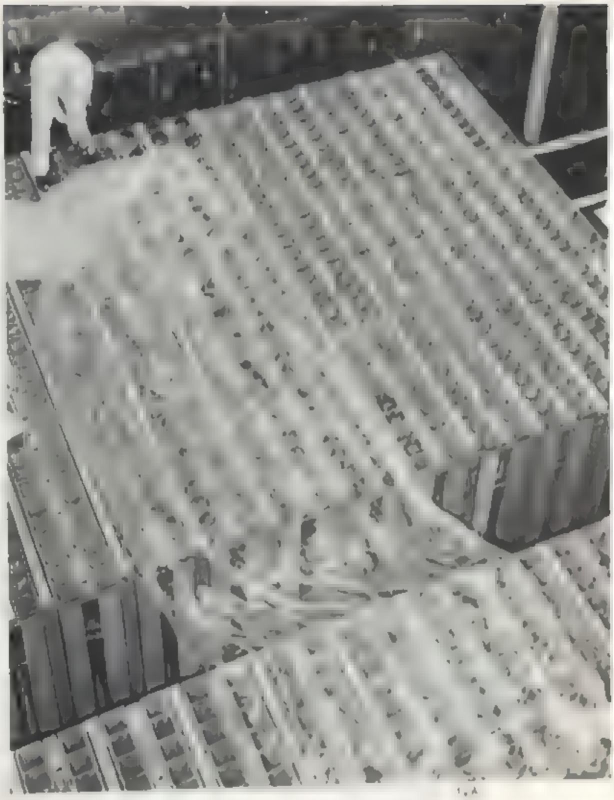
that makes up 0.7 percent of the uranium refined from ore. Plutonium is a man-made fuel. It is available because when an atom of U-238 is penetrated by a neutron, the nucleus becomes U-239, an unstable isotope. It decays to plutonium-239—and plutonium is fissionable. The U-233 used in reactors is derived from the nonfissionable element thorium (Th), with atomic weight 232. When this is irradiated, a thorium atom captures a neutron. The Th-232 nucleus becomes a Th-233 isotope and then decays to U-233. Other elements, such as protactinium, are fissionable, but they have various peculiarities that make them unsuitable for use as nuclear fuels.

At present, all power, propulsion, and research reactors use U-235. It is not an absolutely pure form of this isotope, however. As a matter of fact, most power reactors today operate either on natural uranium, which is mostly nonfissionable U-238 and only 0.7 percent U-235, or on *slightly enriched* uranium, in which the U-235 component has been increased to about 2 to 4 percent.

Most of the world's uranium enrichment is carried on by the gaseous diffusion process. Pure uranium is first converted into uranium hexafluoride (UF_6), because in this form it vaporizes easily. The UF_6 is converted into a gas and pumped through a long series of very fine filters. As the gaseous uranium is forced through the first filter, the U-235 atoms have a tendency to pass through the minute holes more readily than the U-238 atoms because they are lighter. Half the gas is then passed to the next "higher stage" barrier, while the rest is ducted back, to be pumped through the next "lower stage" barrier. The gas moving forward contains more and more U-235, less and less U-238; the gas moving backward, the reverse. In this way, high concentrations of U-235 can be obtained. For practical purposes, uranium containing 93.5 percent of U-235 is considered *fully enriched*, though higher enrichments have been achieved.

In the case of special-purpose reactors, compactness is a higher-priority requirement than low cost. This is true, for example, in the case of submarines or of mobile power plants that can be flown to remote regions. In such cases, fully enriched uranium is preferable. It permits the most compact design, because the core, or fuel charge, contains a maximum of fissionable material and a minimum of nonfissionable U-238. It also permits, potentially, the longest fuel life before refueling is necessary.

However, for commercial purposes, the highly enriched fuel is not economical, because the price of uranium rises in direct proportion to its degree of enrichment. U.S. reactor designers have found that *low-*, or *slight-, enrichment* fuel having a concentration of from 2 to 4 percent U-235 (enriched from 0.7 percent) is an effective compromise. Virtually all U.S. commercial power reactors use slightly enriched fuel.



Fuel storage facility. Nuclear fuel is kept in a specially contructed storage pool. It is frequently inspected while it is in storage

Not all reactors employ slightly enriched uranium, however. Most commercial reactors built in Great Britain, France, and Canada operate on natural uranium—with 99.3 percent U-238 and 0.7 percent U-235.

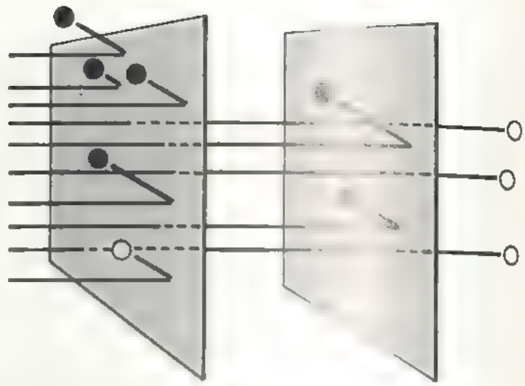
Nuclear fuel—totally unlike any of the fossil fuels, such as coal, oil, and natural gas—must be designed and fabricated with extremely high precision. As a matter of fact, the design and management of high-performance nuclear fuel has been—and still is—a central problem of nuclear power technology and economics.

To begin with, uranium produces fission fragments when it splits, and these are highly radioactive. To keep them from contaminating the coolant stream and spreading radioactivity through the system, the uranium fuel is encased, or *clad,* in a protective sheath of metal. This may be aluminum, stainless steel, or zirconium (usually a zirconium alloy called zircaloy). The cladding serves also to lend strength to the fuel and to protect the uranium from erosion or corrosion by the coolant stream.

Designers of nuclear power reactors in the United States have found that, for large power reactors, uranium in the form of uranium dioxide (UO_2) has advantages over uranium in the form of a metal. Today in the United States, almost all commercial power reactors use this type of fuel. The UO_2, a black powder, is compressed into very dense pellets about 13 millimeters long and eight millimeters in diameter. These fit into tubes three to five meters long. Caps are welded over the ends of the tubes. Free neutrons can pass through the tube walls. The rods are fastened together in bundles of 30 to 300 to form fuel elements. Each bundle weighs 140 to 680 kilograms. A commercial power reactor contains 45 to 136 metric tons of fuel.

MODERATORS

Neutrons liberated by fission of uranium atoms possess a large amount of energy and travel at high speed. If not slowed down, they can escape from the core or be absorbed by U-238 atoms, which do not undergo fission. To slow the neutrons



○ = U-235 ● = U-238

Diagram illustrating the principle of the separation of fissionable U-235 from nonfissionable U-238 through gaseous diffusion. Gas that has been formed by combining uranium and fluorine (UF_6) is pumped through a series of barriers with extremely fine pores. A tiny part of two such barriers is shown here. The U-235 atoms are lighter than the U-238 atoms and pass through the minute holes more readily. The atoms that have penetrated the first barrier are then passed through the other ones. In this way the U-235 concentration increases.

enough for efficient capture by U-235 atoms, moderators such as ordinary or light water, heavy water, or graphite are employed. Heavy water is a combination of oxygen and deuterium, a heavy isotope of hydrogen with an atomic mass of 2. The neutrons slow down when they collide with and give up energy to these lighter elements. This is much like a billiard ball slowing down after it bounces off other balls. The moderated neutrons, which travel only a few kilometers a second, are called *slow,* or *thermal,* neutrons.

Certain reactors use *fast* neutrons, unslowed by a moderator, to cause fission. However, most reactors include moderators. In the majority of U.S. power reactor designs, the water flows through the core as the coolant and does double duty as the moderator. In the prevailing power reactor type built in France and Great Britain, the moderator is graphite, and there is a separate cooling system. Canada favors a type in which the uranium fuel is immersed in a tank of heavy water. In this case, the moderator does not act as coolant. Separate circuits of normal, or light, water are piped through the moderator tank and through the fuel core in order to provide cooling.

COOLANTS

A coolant must conduct heat well without absorbing free-moving neutrons. Water has many desirable properties for this purpose. It is abundant and cheap. It serves as an efficient moderator by slowing down, but not absorbing, neutrons. Light water is preferred in U.S. reactors produced commercially on a large scale. In a typical U.S. nuclear power plant, the water is pumped through the spaces between the fuel rods. Not only does it cool the rods to prevent their overheating, but it also transfers heat to a boiler, where water in a separate system is heated to steam. The steam drives the turbine that is attached to the electric generator.

Two water-coolant systems are used: the so-called *pressurized-water* and *boiling-water* reactor types. In the former, the coolant water that circulates through the reactor is kept under high pressure to keep it from boiling. It is circulated to a *heat exchanger* or *steam generator*. Here it gives up its heat, through metal tubing, to a separate "secondary" loop of water, which boils and is piped to the turbine. The reactor at Three Mile Island in Pennsylvania is a pressurized-water reactor. The accident that occurred there in 1979 resulted in a failure of a pump to supply water to the secondary loop, for a time threatening to overheat the reactor.

In the boiling-water reactor, the heat exchanger and secondary circuit are eliminated. The reactor coolant water boils to steam and is piped to the turbine.

Gases such as carbon dioxide or helium can be used as coolants. Unfortunately, they do not transfer heat nearly so well as liquids do. Carbon dioxide gas (CO_2) is employed as the coolant in most British and French reactors, in which natural uranium is the fuel. In these reactors, graphite is the moderator. The graphite blocks are stacked to form a core structure. The carbon dioxide, heated during its passage through the core, goes to a heat exchanger, in which it boils water to steam.

Liquid metals have also been used as coolants. Sodium is favored because it has

General Electric

This photograph gives a close-up of uranium dioxide fuel pellets destined for a nuclear power plant The pellets shown here are the equivalent of more than 85 metric tons of coal

a comparatively low melting point and is effective in heat transfer. It is abundant and comparatively inexpensive. It is particularly suitable for fast-neutron reactors. In reactors using sodium as the coolant, graphite is generally used as the moderator.

Elements that absorb neutrons, much as a blotter absorbs water, include boron, cadmium, hafnium, and the rare earths gadolinium and europium. They are fabricated into rods or blades that can be made to slide up and down, in and out of the core of nuclear fuel. As they are inserted farther into the core, they absorb neutrons that otherwise would cause fission. In this way they slow down the chain reaction. If they are inserted all the way in, they stop the reaction, shutting down the reactor. Conversely, as they are pulled out, the number of neutrons available for fission increases, and the reactor power level goes up.

SAFETY PRECAUTIONS

Rods that function like control rods can be quickly inserted into the core in an emergency. They rapidly absorb enough neutrons to stop a chain reaction. An operator in the control room presses a button to insert these *safety rods*. They also are activated automatically when certain conditions occur, such as an abnormal increase in the fission rate. Similarly, tiny balls

ndustrial Forum, Inc

Spent fuel assemblies, in impact resistant casks, arrive at a site in Nevada being used as a test repository to evaluate nuclear waste-management procedures.

made of a neutron-absorbing material can be dropped into the core to effect an emergency shutdown.

Most reactors also have an emergency *core-cooling system* to prevent the core from overheating if the coolant is lost. This system floods the core with water to prevent melting and release of dangerous radioactive materials. In addition, the pressure vessel sits in a leakproof containment shell or building. Radioactive particles that get into this structure are cleared away with filters or other devices.

REPLENISHING FUEL

Nuclear fuel, like any other kind of fuel, must be replenished. The slightly enriched uranium now being fabricated for commercial power reactors could keep a reactor going for years without a halt. However, power companies find it more efficient to reload one-third of the core each year.

When the core of the typical nuclear reactor needs replacement, only 1 to 4 percent of the available atoms have been fissioned. However, by that time, the new elements formed when a uranium atom is split in two are competing to absorb neutrons. This parasitic capture of neutrons rises to a level where it begins to damp out or cut down the reactor power.

More than 90 percent of the fissionable atoms remain intact when the fuel is removed. These radioactive atoms and the radioactive products of fission generate a large amount of heat, so the fuel rods are put into storage pools for cooling. Until 1977, this waste was then reprocessed to recover the unfissioned U-235 and the plutonium formed in the U-238. In that year, the federal government placed a ban on commercial reprocessing. This was done to prevent plutonium from being stolen and used by terrorists or others to make nuclear bombs.

The ban was lifted in 1981, but private companies continued to store most of their spent fuel rods in pools near the reactors where they had been used. Industry does not want to invest in expensive new reprocessing facilities because the ban might be

reinst[illegible]l and because the future of nuclear power [illegible] the United States has become uncertai[illegible]

WAST[illegible] [illegible]ISPOSAL

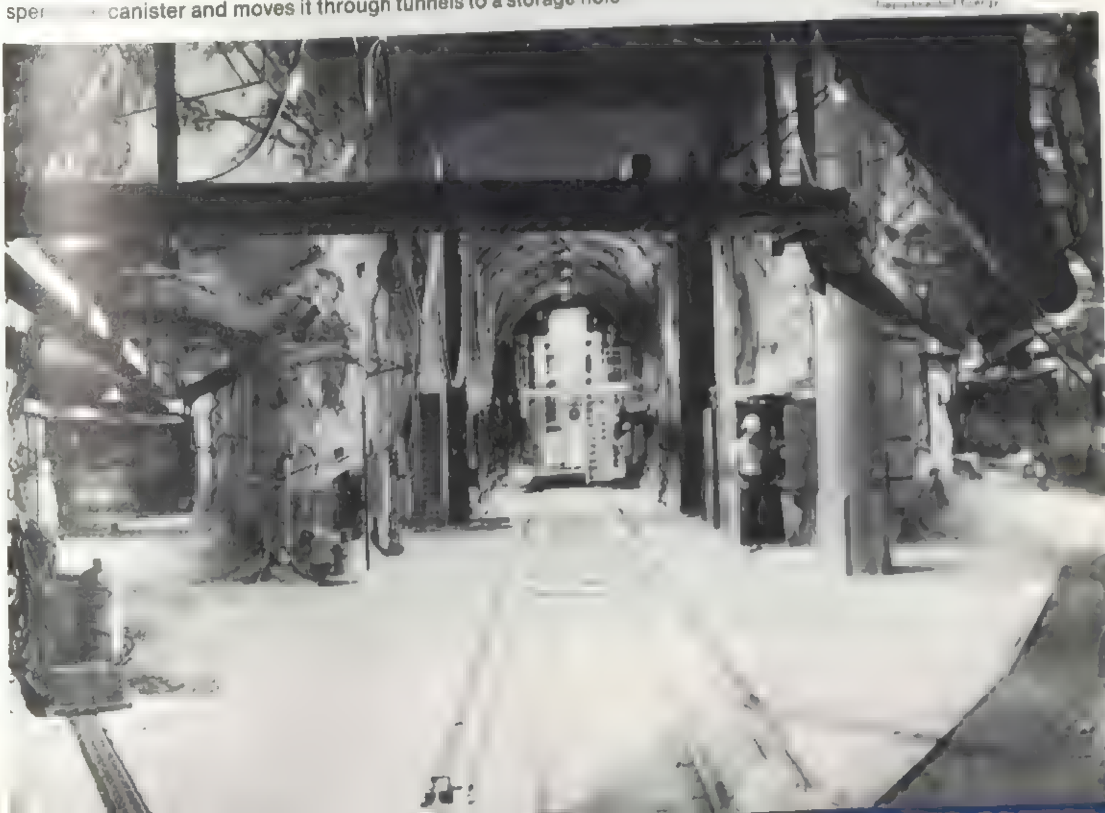
R[illegible]rocessing does not solve the waste probl[illegible] After removal of the fissionable mater[illegible] highly radioactive fission products a[illegible]other dangerous materials remain. This t[illegible]e of waste, generated by both industr[illegible] and the military, has accumulated for al[illegible]t 40 years. No national plan existed [illegible] its disposal until Congress passed the N[illegible]ear Waste Policy Act in December 1982[illegible]s legislation establishes a schedule for p[illegible]anent, deep-underground storage of nu[illegible]r wastes by the 1990's.

[illegible]. facilities will be constructed to test [illegible]valuate methods of containing the wast[illegible] he facility will test repositories mined in salt, basalt, granite, and rock form[illegible]rom volcanic ash. The Department of [illegible]gy (DOE) must then recommend thre[illegible]ndidate sites for full-scale permanen[illegible]ste storage. The president would cho[illegible] the first site in 1987. A second site would be selected in 1990 from five other candidate locations submitted by DOE before July 1, 1989.

The bill deals specifically with commercial waste. However, it provides a mechanism for storage of wastes from military nuclear programs, which produce more radioactive waste than industry does. For utilities that run out of on-site space in the interim, the act provides for temporary storage of wastes at existing federal facilities. The latter must be located away from any nuclear reactor, and storage is limited to 1,900 metric tons of spent fuel at each site. One commercially operated facility exists at Morris, Illinois. In addition, the bill requires DOE to propose three to five sites for "monitored, retrieval storage." Spent fuel would be stored here until a decision is made whether to send it to a reprocessing plant or to an underground repository.

Several European nations plan to encase high-level waste in glass or ceramic as a first step in disposal. A plant at Marcoule, France, combines wastes with the ingredi-

At a[illegible] underground Nevada test site, a rail-mounted cask vehicle receives the spe[illegible] canister and moves it through tunnels to a storage hole



Department of Energy

Workers at a nuclear-waste test storage site in the state of Washington stack large metal containers of low-level radioactive waste from various sources

ents used in making glass. This *vitrification* process provides resistance against the heat generated by radioactivity as well as against chemical action and erosion produced by external factors such as groundwater. The vitrified wastes are sealed in metal containers, then stored in air-cooled wells. Future plans call for transferring this waste to deep underground caverns when it has cooled to a point where no dangerous buildup of heat will occur.

The United States plans to package military wastes in much the same manner. Liquid wastes, now encased in double-walled steel tanks at four sites, would be solidified into glass or ceramic. DOE's schedule calls for the first high-level waste immobilization plant to be in operation by 1988.

Spent fuel rods, however, are not in a form that can be handled by such a plant. Possible alternate treatments range from packaging entire rods intact to chopping them up, dissolving the fuel in acid, converting it to glass, enclosing it in metal containers, then burying it in the repositories. The buried wastes remain dangerous for a long time. Fission products such as cesium and strontium require 600 years before they cease to be radioactive and decay into stable isotopes. If the fuel is not reprocessed, plutonium-239 will remain dangerous for 24,000 years. Other heavy elements take even longer to decay.

BREEDER REACTORS

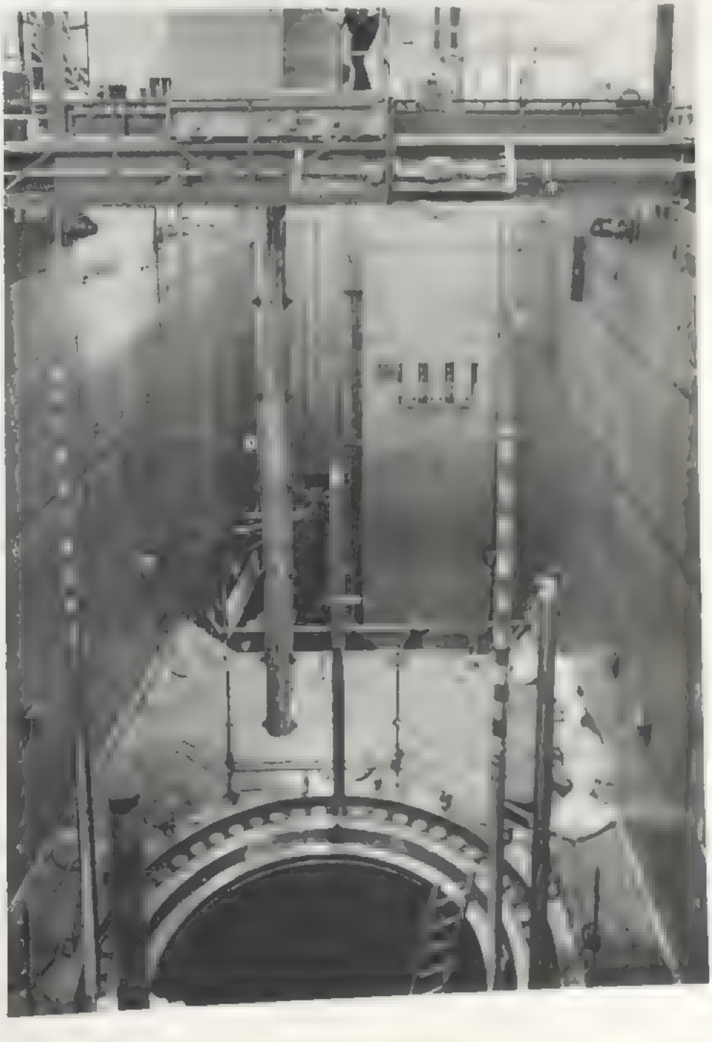
It would be much better to use plutonium as a fuel than to bury it. Special reactors can, in fact, produce more plutonium fuel than the U-235 they use to generate power. Such *breeder reactors* offer the intriguing prospect of indefinitely extending the earth's supply of uranium, expected to be depleted early in the next century. The first power-producing reactor ever built was a breeder. The Experimental

Breeder Reactor (EBR) No. 1, completed by the United States in 1951, used fast neutrons to produce Pu-239 in a U-238 blanket that surrounded its U-235 core. Although it produced slightly more plutonium than the uranium it used, EBR-1 was only a small reactor built for demonstration purposes.

France, West Germany, Great Britain, Japan, and the Soviet Union also have constructed experimental breeders. The most successful one is a French reactor that produces plutonium and 250 million watts of electricity. It was named Phénix for the mythical bird that rose to a new life from the ashes of a fire that consumed it. No country, however, has overcome all the technical obstacles in the way of producing a full-scale commercial breeder.

France is closest to this goal, with construction of the 1.2 billion-watt Super Phénix, scheduled to be completed in the mid-1980's. The United States has fallen behind other nations in this area. Proponents of nuclear power want to build a 350 million-watt demonstration breeder at Clinch River in Oak Ridge, Tennessee. However, the project faces strong opposition on the grounds that the plutonium might be stolen or given to nations who would use it for nuclear weapons. Enthusiasm for breeders

Pacific Gas and Electric Co



Detailed testing is done before nuclear fuel is placed in a reactor. During the extended period of testing, power to run the plant will come from non-nuclear sources.

also has waned because safety concerns and high costs have caused the nuclear industry to fall on hard times.

USES FOR NUCLEAR ENERGY

Nuclear energy provided about 1 percent of the world's energy, and nuclear power plants generated about 9 percent of the world's electricity in 1983. These percentages were expected to increase as more countries build more reactors.

Nuclear energy has been used to propel ships since the United States launched the first nuclear-powered ship—the submarine *Nautilus*—in 1954. Nuclear subs can remain submerged for months, while conventionally powered craft must approach the surface to run their diesel engines or charge batteries. The advantage is so significant that the U.S. Navy ordered only "nuke boats" after 1955. The Soviet Union also possesses a large fleet of nuclear-powered submarines.

U.S. naval vessels include nuclear-powered aircraft carriers and other ships that can travel around the world without refueling. The Soviet Union operates a nuclear-powered icebreaker. The U.S. launched the *Savannah*, the first nuclear merchant ship, in 1959. However, such merchant ships proved impractical because of high construction and operating costs. The *Savannah* was retired in 1971.

Low-power research reactors are employed for basic investigations of the effects of radiation on living and nonliving materials. Higher-power machines irradiate materials and parts to determine their suitability for new types of reactors.

Radioactive isotopes that do not occur naturally are made in nuclear reactors and particle accelerators. These serve in medical diagnosis and treatment of disease. They are widely used to detect tumors and to destroy cancerous cells. Radioisotopes can replace common stable isotopes in chemical and biological reactions, making them ideal for tracing what happens in these reactions. Radioactive carbon and phosphorous, for example, are used to trace the path of these elements during the growth of plants. Radioisotopes released by now-banned nuclear bomb tests in the atmosphere have been used to track the movement of deep ocean waters.

Industrial companies use radioisotopes to find microscopic flaws and cracks in metals and welds. They also measure the thickness of materials. Detectors on one side of an object measure radiation that penetrates it. The thinner the material or the more flaws present, the greater the amount of radiation recorded.

STATUS OF NUCLEAR POWER

Research, testing, and other specialized reactors appear to have a brighter future than power reactors in the United States. Public concerns about safety—particularly after the Three Mile Island accident—and environmental contamination have caused the Nuclear Regulatory Commission (NRC) to mandate new safety requirements and design changes. These in turn have increased the cost of constructing nuclear power plants. The cost of building a nuclear reactor more than doubled between 1977 and 1983. Owners of units already in operation are spending additional millions of dollars to meet new safety standards. No new reactors have been ordered in the United States since the end of 1978. Construction of many plants ordered before this time has been canceled or delayed.

Planners in 1983 allowed twelve years for the construction of a new nuclear power plant, compared to eight years for a coal-fired plant. Plants ordered before 1979 were completed at the rate of two to six a year during the first three years of the 1980's. Electricity generated with nuclear energy exceeded that produced by burning oil in 1980. By 1983, some 80 nuclear plants accounted for 11 percent of the power capacity in the United States.

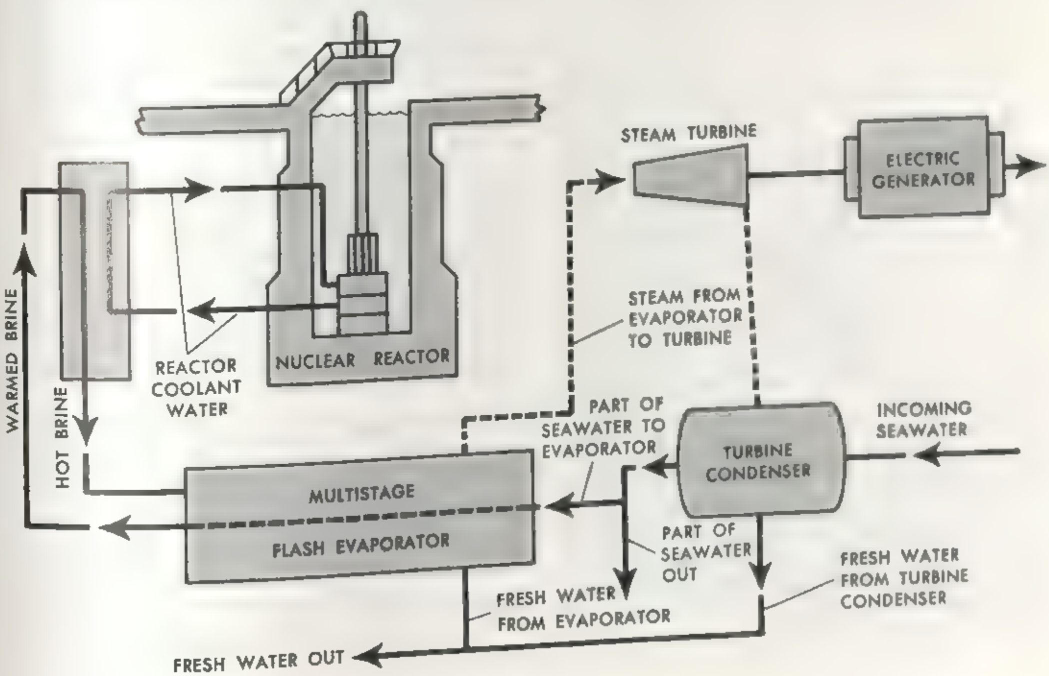
The industry's woes, however, continued to mount. In February 1983, the safety system at a nuclear power plant near Trenton, New Jersey, failed on two occasions, and the NRC called this the worst mishap since Three Mile Island.

Older reactors have developed cracks in their cooling-water systems, necessitating expensive repairs. The U.S. Supreme

Court in 1983 upheld a California law halting the construction of nuclear power plants until resolution of uncertainties over disposal of high-level waste. This decision affirmed the right of a state to stop or prohibit building of nuclear plants, raising the possibility that other states might follow California's example.

Nuclear power fared better in other nations than in the United States during the early 1980's. More than 200 reactors were operating in 24 other countries at the end of 1982. These units generated 9 percent of the world's electricity, or 104,823,000,000 watts. An additional 163 power reactors were under construction. France operated 32 nuclear units, which provided more than 40 percent of that nation's power. Japan was second with 25 units. Other nations with significant nuclear power capacity included Canada, West Germany, Sweden, and the Soviet Union.

This greatly simplified flow chart shows a possible multipurpose nuclear facility that has been designated Surfside. The reactor will produce radioisotopes. It will also provide the heat that is required for a desalting operation and for the generation of electricity by a generator hooked to a turbine. The seawater entering the system will pass through the turbine condenser, providing the cooling element in the condenser. It will bring about the condensation of the steam coming from the turbine. A portion of the seawater will flow to the desalting system. The warmed seawater, now called brine, will pass to a heating system associated with an open-pool ("swimming-pool") reactor. Hot coolant will pass from the reactor to the heating system, bringing the brine to a higher temperature. The brine will pass to a multistage flash evaporator. The resulting vapor will pass through a condenser and will condense into fresh water. The vapor, or steam, that is removed in the last stages will be sent directly to a steam turbine, which is hooked up to the electric generator. After the steam has passed through the wheels of the turbine, it will be condensed. The resulting fresh water will join the fresh water that has been derived directly from the flash evaporator. It is estimated that some four million liters of fresh water should be produced daily at a nuclear plant of this type in operation.



FUSION ENERGY

by William J. Cromie

Nuclear energy is widely regarded as one solution to the world's growing energy problems. Until recently, most discussion of nuclear energy was about nuclear-fission energy—the energy released when the nucleus of an atom is split. There is, however, another nuclear process, not yet harnessed for peaceful purposes, that gives promise of making available even cheaper power. It is the fusion process. The power is derived from an almost limitless fuel supply—the waters of the oceans.

In fusion, two atoms of one of the lightest elements fuse, or combine. This reaction results in the release of a tremendous amount of energy. Nuclear fusion is the reaction that accounts for the energy produced by the sun.

LIMITLESS FUEL

We said that seawater is the fuel for the nuclear-fusion process, but to be accurate, it is the hydrogen in seawater that is the fuel. For the purposes of producing energy for homes and industries, the nuclei of two isotopes of hydrogen would be fused, or combined, to form helium. Deuterium and tritium are the two isotopes of hydrogen.

The supply of deuterium is virtually unlimited, and tritium can be made from deuterium. Deuterium is abundant in seawater. There is one deuterium atom for every 6,500 hydrogen atoms in seawater. It has been calculated that the oceans hold 100 quintillion grams of deuterium.

In terms of conventional energy sources, one kilogram of deuterium oxide, D_2O, a form of water known as *heavy water*, can provide the energy equivalent of 2,000 metric tons of coal, or 1.9 million liters of gasoline. Expressing it another way, the energy produced by the deuterium nuclei in one liter of water is about the same as that obtained by burning 300 liters of gasoline. Considering the amount of deuterium in seawater, there is enough deuterium fuel to supply our energy requirements for several million years.

The cost of extracting deuterium from seawater is not unreasonable, and we know the supply is great. What, then, is the problem?

A CONTAINER

The control of the fusion reaction is proving incomparably more difficult than that of the fission reaction. Even the scientific principles involved in controlling the reaction remain to be worked out. Scientists competent in the field are still trying to achieve a controlled release of fusion power with a positive energy balance. To bring about such a balance, it would be necessary to get more power out of a fusion reaction than would be required to make it.

One prerequisite for a fusion reaction is a temperature of at least 100,000,000° Celsius. At such a temperature, the three states of matter—gas, liquid, and solid—no longer exist. All matter is in a fourth state, called a *plasma*. It consists only of atomic nuclei and free electrons, all flying about at high velocities. This is in fact the state of our sun's interior and that of the other stars.

How is it possible to build a container that will not melt long before temperatures reach 100,000,000° Celsius? Scientists have found two ways. One method confines the plasma with enormous bursts of energy from a battery of lasers. The other uses a strong magnetic force to "bottle up" the hot, electrified plasma. Intense magnetic fields form a bottle or tube inside the container. This keeps the plasma from touching the walls and transferring heat and energy to the container.

THE LASER SOLUTION

In a laser system, deuterium-tritium gas sits in a small, hollow glass pellet. Lasers are arranged around the pellet like spokes radiating from the hub of a bicycle wheel. They all emit high-energy pulses of light at the same time. This energy compresses the fuel explosively, heating it in billionths of a second to millions of degrees.

ERDA's Lawrence Livermore Laboratory

Glass laser amplifier. This unit intensifies the laser beams that will be used to ignite the fuel pellets. Amplifiers may greatly improve results.

Researchers at the Lawrence Livermore National Laboratory (LLNL) in Livermore, California, used 20 lasers to focus 26 trillion watts of power on a 0.5-millimeter pellet for one 10-billionth of a second. The laser device, called Shiva for a Hindu god that represents a creative force, fell short of starting a fusion reaction. LLNL scientists plan to try again with a system called Nova. Named for an exploding star, Nova will have 10 times more power when it is completed in the late 1980's.

Physicists at the Sandia National Laboratory in Albuquerque, New Mexico, substitute beams of protons for laser beams. Streams of these positively charged particles from the nuclei of atoms deliver power pulses of billions of watts. The Sandia group plans to create a controlled fusion reaction by hitting a 0.5-centimeter pellet with 100 trillion watts generated by 72 particle beams. The big event may occur before the end of the 1980's.

MAGNETIC BOTTLES

Magnetic bottles come in two varieties —tubular and doughnut-shaped. The ends of tubular reactors are "plugged" with interlocking magnets. These, together with magnetic fields that are stronger at the ends of the tube than in the center, keep the plasma from leaking out. The magnetic fields cause plasma particles to be reflected in the tube as if by mirrors. Beams of neutral particles (having no electric charge) are shot at the plasma, collide with it, and heat it to fusion temperatures. These "bullets" must be neutral to penetrate the magnetic field containing the plasma.

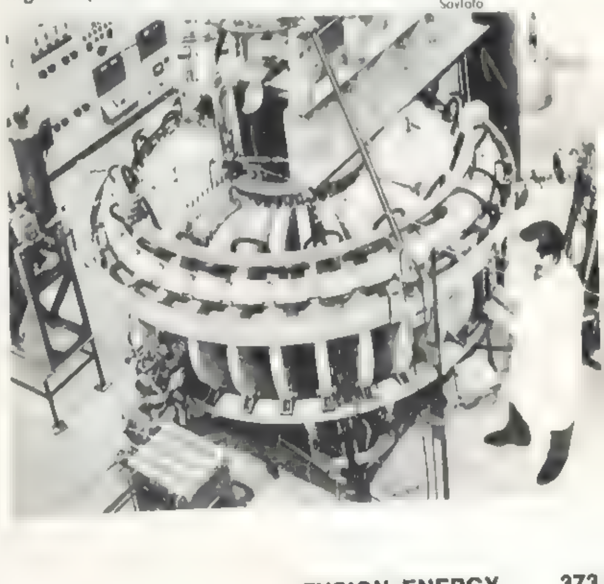
Scientists have experimented with magnetic mirrors since the early 1950's. U.S. experimenters who favor this method are betting on the success of the Mirror Test Facility being built at LLNL. It is expected to be completed by 1986.

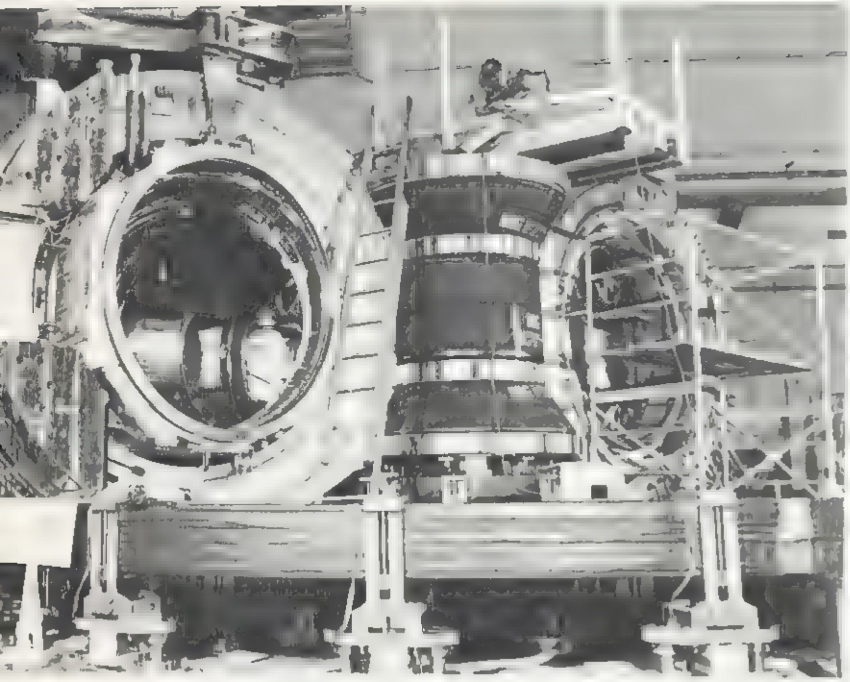
If a magnetic tube is bent until its ends join, the result is a toroidal, or doughnut-shaped, bottle having no ends from which plasma can leak. The toroid can be effectively combined in various ways with electromagnets and heat sources utilizing electric currents, neutral beams, or radio waves. One major design is known by the Russian name *tokamak* because it was the idea of Soviet scientists. A number of tokamaks have been built in different countries.

The U.S. effort in the early 1980's centered on the Tokamak Fusion Test Reactor at Princeton University in Princeton, New Jersey. If operations proceed as planned, this $500 million machine should reach the

The Soviet Union has developed the Tokamak, a magnetic container that can hold plasmas at very high temperatures over a long period of time.

Sovfoto





Princeton Plasma Physics Laboratory

This view shows the support structure for the magnetic vessel during the installation of Princeton University's new Tokamak Fusion Test Reactor

"break-even" point in the late 1980's. This means it would produce as much energy from fusion as it takes to confine and heat the plasma.

A WORLDWIDE EFFORT

At the Oak Ridge National Laboratory in Oak Ridge, Tennessee, physicists are working on a design known as the Elmo Bumpy Torus. The name comes from the fact that the plasma inside the torus is squeezed into a series of bulges or bumps. Another type of magnetic bottle, being tested at the Los Alamos National Laboratory in Los Alamos, New Mexico, goes by the name Reversed Field Pinch. Physicists at Princeton and in West Germany experiment with stellerators. A stellerator is shaped like a torus twisted into a figure eight.

A group of European nations will try to produce fission energy in the 1980's with the Joint European Torus (JET). The Japanese have been doing experiments with a tokamak called simply JFT-11. They are spending $1 billion to build a bigger and better tokamak–the JT-60. The Soviets, who have several decades of experience with tokamaks, continue to develop newer models.

Together, these countries spent $2 billion on fusion projects in 1982. The U.S. Magnetic Fusion Engineering Act of 1980 provided about one quarter of this total. The cost will be worthwhile if fusion lives up to its promise of cheap, unlimited energy.

Other advantages include much less radioactivity than in fission reactors, and no danger of explosion. If the process should get out of control, energy and temperature levels will fall to the point where the reaction stops. Tritium is slightly radioactive, but it is much less hazardous than the plutonium produced by the fission reactors now used to generate power. The reactor itself would become radioactive, but the amount of radioactive material would be about 100 times less than that of a fission reactor producing the same amount of power.

Experts believe that a fusion system with positive energy balance will become a reality before 1995. Then, early in the next century, the energy of the stars should be available to run our factories and heat and light our homes and businesses.

ALTERNATE ENERGY SOURCES

by William J. Cromie

The earth is like an automobile running out of gas as it speeds down the road to the future. New deposits of petroleum, the source of fuel oil and gasoline, had become difficult to find by the early 1980's. Experts predicted that costs for petroleum products would increase as they became scarcer and that usable sources would run out early in the 21st century. Natural gas can be substituted for petroleum in many cases, but it, too, was expected to be depleted before the middle of the century. The uranium that fuels nuclear reactors may not last even that long.

The world's supply of coal, our most abundant fuel, is expected to last 300 to 400 years. This has encouraged research into methods of converting it into a liquid that can replace petroleum, or a gas that can replace natural gas. In a typical *gasification* process, powdered coal is mixed with steam and oxygen under high pressure. This produces a mixture of carbon monoxide, hydrogen, and methane that can be used like natural gas. The first commercial plant to be built for this purpose will be located near Beulah, North Dakota. The Great Plains coal gasification plant is expected to convert 19,800 metric tons of coal a day into 3,537,500 cubic meters of synthetic gas.

Coal *liquefaction* processes convert coal into a gas or *slurry* (thin slush). Then hydrogen is added to break down the coal molecules and turn them into a liquid. Coal also can be gasified and converted into methyl alcohol, a substitute for gasoline.

SYNTHETIC FUELS

Synthetic fuels, or *synfuels*, also can be made from oil shale, tar sands, and *biomass*. Oil shale, a soft, fine-grained rock, contains *kerogen*, from which oil and gas can be obtained by heating. Tar or oil sands contain *bitumen*, a thick black substance that can be made into oil or gas. Biomass refers to plant or animal matter from which energy is released by heating or chemical reaction.

To encourage development of synfuels as an alternative to dwindling resources of petroleum and natural gas, the United States formed the Synthetic Fuels Corporation (SFC) in August 1980. The SFC provides money and other types of assistance to private businesses that work to develop commercial synfuel projects. The first of these projects involves extraction of kerogen from the Green River shale formation. One of the world's largest deposits of oil shale, the Green River formation occupies parts of western Colorado, eastern Utah, and southern Wyoming.

SFC will also deal with attempts to obtain hydrogen fuel from water by *electrolysis*. This involves splitting water into hydrogen and oxygen gas with an electric current. Hydrogen burns hot and clean, eliminating the air pollution caused by coal and oil. In the burning process, hydrogen recombines with oxygen, yielding water, not ash or smoke, as a combustion product. The cycle then can be repeated. One major barrier stands in the way of this cheap, clean, inexhaustible fuel source: it now requires more energy to obtain hydrogen by electrolysis than the gas gives up during combustion.

Scientists have devised various ways of breaking down this barrier by using sunlight instead of electricity to split water. By mid-1983, no researchers had gotten out more energy than they had put into such a system. Many experts, however, believe that this will be accomplished before the end of the century.

BIOMASS AND GASOHOL

Scientists from the Department of Energy (DOE), from industry, and from universities are studying various ways to wrest energy from biomass—land and water

netic field, this gas produces an electric current that can be fed into power lines. This eliminates the boilers, turbines, and generators that are otherwise used to produce electricity. Because of this efficiency, an MHD generator produces 50 percent more energy from a ton of coal than does a conventional power plant. However, no one has yet devised a way to build parts that can withstand the extremely high temperatures needed to produce the hot electrified gas.

Another solution involves *breeder reactors*, which produce more nuclear fuel than they use. Breeders offer the promise of extending known resources of uranium indefinitely. However, these reactors produce *plutonium*, the "powder" used in nuclear weapons. Fear that plutonium could fall into the wrong hands and the difficulties in preventing this have almost halted development of breeders in the United States.

Nuclear power also brings with it the problems of disposal of dangerous radioactive wastes, as well as safety and environmental hazards created by operating power reactors. Nuclear *fusion* avoids these problems for the most part, but it requires extremely high temperatures (100,000,000° Celsius) to convert hydrogen in seawater to useful energy. Fusion power may become a reality early in the next century. (See the article "Fusion Energy.")

Using natural heat within the earth offers another solution. So-called *geothermal* energy comes from steam produced when water contacts hot subterranean rocks. Like geothermal energy, heat from the sun is an inexhaustible form of energy. All we need to do is determine how to harness it effectively. (See the articles "Geothermal Energy" and "Solar Power.")

HARNESSING THE TIDES

Tides, like the sun, always will be with us, and people have utilized the energy in their ebbs and flows since at least the 11th century. For centuries the moving waters turned mills that ground grains. Utilizing tidal power on a grand scale to generate electricity, however, did not become a reality until 1966. That year France began full operation of the world's first tidal-power plant, located at St. Malo on the English Channel.

Such plants require tides with a large range flowing in and out of a narrow bay or river that can be closed off by a dam. High tides raise water in the bay or river, which is closed by the dam before the water begins to ebb. During low tide, the water level outside the dam drops below the level in the bay. Gates are opened, and as the stored water falls to a lower level, it drives turbines that generate electricity.

Tides come and go, but people need a continuous flow of electricity. To get it, the falling water is made to operate pumps that put water into storage ponds for release between tidal cycles.

North America's first tidal-power plant is planned for Annapolis Basin on the west shore of Nova Scotia, Canada. Here tides with a maximum range of 8.7 meters bring water into the Annapolis River. As it flows out again into the Bay of Fundy, the water will spin turbine generators expected to produce 20 million watts of power. If successful, this plant could pave the way for larger tidal-power plants at the head of the Bay of Fundy where tides range 15 meters. Such power plants, however, are not likely to claim a large share of the world's power capacity because they can be constructed only in a limited number of places

FUTURE OUTLOOK

Which alternative forms of energy will prove feasible, and when, depends on many factors. Some of these forms will be geographically limited to areas rich in source materials such as wood, corn, or tides.

Oil and natural gas now provide about 70 percent of the world's energy. For the next 25 to 50 years, only nuclear energy and coal-based synfuels show promise of replacing a large slice of the energy pie. Beyond A.D. 2025, fusion and solar power seem to hold the greatest potential, but the alternatives are many. Undoubtedly, human ingenuity will develop the combination needed to keep the lights on and the wheels turning, albeit at a higher price.

THE SOLAR BATTERY

Our star, the sun, radiates energy at an enormous rate. The earth is so small, comparatively speaking, and so far away from the sun that it receives only about 1/2,000,000,000 of the energy. Yet even this represents a staggering quantity.

We would be able to put our slim quota of solar energy to even better use if we could harness it effectively. Much progress is being made in this respect. Heat produced by the sun's rays has served to generate electricity indirectly, to provide warmth for houses, and even to cook food. Solar energy is made to heat a liquid. The resulting vapor runs turbines which are connected to generators of electricity.

In the useful device called the *photoelectric cell*, the light of the sun as well as light from other sources has been converted directly into electric energy. The electric power produced by the photoelectric cell is very feeble. A far more effective device for generating electric power from sunlight is the solar battery. A solar battery is made up of a number of cells, each consisting of a wafer of pure silicon, to which certain impurities have been added.

WANDERING ELECTRONS

To have some idea of the workings of a solar cell, let us recall that electrons—particles with a negative electrical charge—revolve around the nucleus of a typical atom in several concentric shells. Atoms combine with one another through the agency of the electrons that make up the outermost shell. A silicon atom has four electrons in this shell. In a silicon crystal, each atom is normally joined to four of its neighbors by its four outer electrons.

If an electron is jarred loose from a silicon atom by some outer force such as light, heat, or electrical energy, it will wander freely through the crystal, leaving a hole in the crystal lattice, or framework. This hole behaves like a positive charge of electricity. Every time an electron from an adjacent atom moves in to fill such gap, it leaves a new gap behind it. In this way holes can travel from one part of the crystal to another, just as electrons can. When we apply an outside source of energy to a crystal, therefore, a certain number of freely wandering negative and positive charges are created

The production of silicon solar cells has been advanced by the successful growth of a continuous ribbon of crystalline silicon

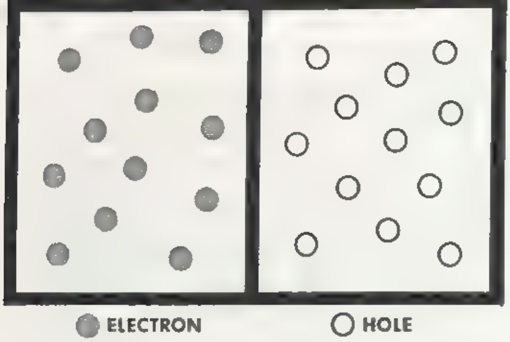


Fig. 1. If we put arsenic in half of a silicon wafer (A) there will be more electrons than holes. If we put boron in the other half (B), there will be more holes than electrons. "Electrons" and "holes" are explained in the text of the article.

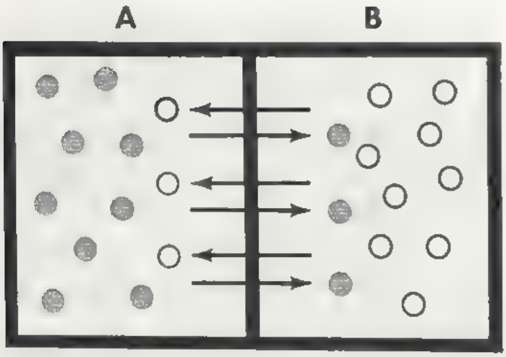
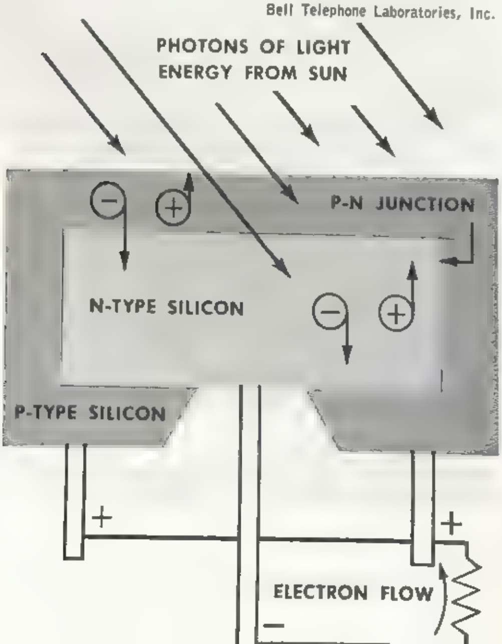


Fig. 2. The negative electrons and positive holes cross the boundary between A and B. Side B will acquire a negative charge as the electrons pass into it. Side A will acquire a positive charge as it receives holes from B.

Fig. 3. Typical silicon solar cell, described in the text.

Bell Telephone Laboratories, Inc.



within the crystal. They travel at random and balance one another.

Suppose that we introduce a trace of arsenic in a silicon crystal. The arsenic atom has five electrons in its outer shell. If it combines with four adjacent atoms of silicon (just as a silicon atom would combine with its neighbors), one of the arsenic electrons will be left over and will become a free electron. Even a trace of arsenic contains a very large number of atoms. Therefore we bring about an excess of freely movable electrons by introducing the arsenic. The crystal as a whole remains electrically neutral, since the extra free electrons are balanced by positively charged protons in the nuclei of the arsenic atoms.

There would be a different state of affairs if we put boron in the crystal. Each boron atom has only three electrons in its outer shell. If it combined with four silicon neighbors, the lack of one electron would leave a positive hole in the crystal lattice around the boron atom. As we would be introducing considerable numbers of boron atoms in the crystal, we would now have an excess of positively charged holes. Again, the neutrality of the total crystal would not be affected.

CREATING A FIELD

Suppose now that we put arsenic in one half of a silicon crystal (*A* in Figure 1) and boron in the other half (*B* in Figure 1). Each half of the crystal would be electrically neutral. Yet the concentration of free electrons would be greater in the arsenic half than in the boron half. Similarly, there would be more wandering holes on the boron side than on the arsenic side. Since both kinds of charges move about in a haphazard way, they would tend to diffuse throughout the entire crystal, crossing the boundary between *A* and *B*. Side *B* would acquire a negative charge because excess electrons would be passing into it. Side *A*, on the other hand, would become positively charged, since it would receive an excess of holes. (See Figure 2.) These charges would build up as more electrons and holes passed through. In time they would become strong enough to prevent any more diffusion at the

GTE Lenkurt Inc

Telephone service to a remote community has been made possible by the solar-powered microwave repeater shown above. The arrays that convert light to electrical power are being inspected.

UPI

Solar power can also be used in transportation. The photo shows solar cells being used to convert the sun's rays into electrical power to control track circuits along part of the Canadian railroads

boundary. Negatively charged side *B* would repel electrons. Positively charged side *A* would repel holes. Equilibrium would be established and we would now have a built-in *electric field*, as the inventors of the solar battery call it.

We have just such an arrangement in each of the cells that make up the solar battery. Each cell (Figure 3) is a thin wafer. Its body consists of silicon with a trace of arsenic. This is called n-type silicon ("n" = "negative") because the addition of the arsenic provides an excess of negative charges. The surface of the wafer is made up of a thin layer of silicon with a trace of boron. This is called p-type silicon ("p" = "positive") because it has an excess of positively charged holes. The boundary between the silicon-arsenic body and the silicon-boron surface is called the p-n junction. The p-type silicon, corresponding to *B* in Figure 1, develops a negative charge; the n-type silicon, corresponding to *A*, develops a positive charge.

PRODUCING A CURRENT

To use the solar battery, terminals are attached to the n-type and p-type material, as shown in Figure 3, and the terminals are connected by wiring. When sunlight strikes the surface of the wafer, it knocks out electrons from the crystal lattice in the vicinity of the junction and produces electron-hole pairs. In so doing it upsets the equilibrium established between the n-type and the p-type silicon. Electrons are pulled across the junction into the n-type silicon, and holes are pulled into the p-type silicon. Electrons

then stream from the negative terminal by way of the electric wiring to the positive terminal. Current will flow in this way as long as sunlight strikes the silicon wafer. Practical solar batteries consist of a number of such wafer-cells set side by side and electrically connected in series.

EFFICIENCY

The most efficient solar cells available can convert 1,000 watts of sunlight into 180 watts of electricity. This is 18 percent efficiency. Solar cells used in space—for example, on orbiting satellites—are somewhat less efficient. They convert about 15 percent of the sunlight into electricity.

EXPANDING USE

Solar cells have been used in space-exploration operations. They have been used quite extensively in artificial earth satellites to provide electric power for various satellite operations. Most communications satellites now functioning use solar cells to provide a portion of their electrical power needs.

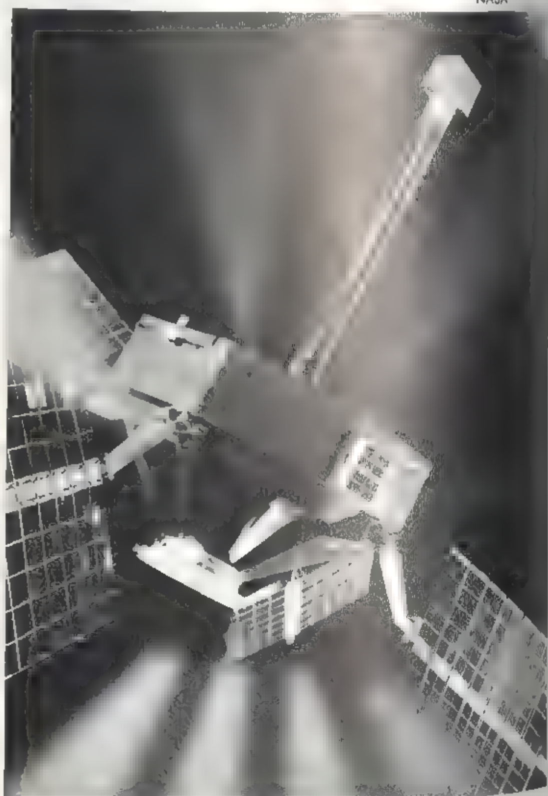
Increasing concern over the earth's energy resources has spurred interest and research on ways of using solar cells to provide electrical energy on a large scale. It is believed that as the solar battery is perfected, it will find many useful applications. It should offer some striking advantages. It has no moving parts or corrosive chemicals, such as we find in various other generators of electricity. Hence it should have an unusually long life. Besides, the sunlight on which it operates is our most abundant resource.

An engineer prepares to attach solar cells and transparent sapphires to a model of a communications satellite. The use of solar cells enables satellites to keep working for long periods of time.

Bell Telephone Laboratories

Model of NASA's Energetic Particles satellite. When orbit is achieved, mechan[illegible]ns extend to place panels of solar cells in position. These cells provide power for the satellite

NASA



ELECTRICAL ENERGY

by Bernhardt G. A. Skrotzki

The form of energy that we call electricity performs an endless variety of tasks in our homes. It powers radios, television receivers, stereo systems, and telephones. It works front-door chimes and back-door buzzers. Electric motors run our clothes washers, dishwashers, ventilating and circulating fans, and many other devices. Electricity supplies our homes with light. It provides heat for toasters, rotisseries, coffee percolators, and other equipment.

Outside the home, too, electricity is just as indispensable. It illuminates our streets and highways. Electric motors run the elevators that have made towering skyscrapers possible. Electricity runs adding and billing machines. It powers the electronic calculating machines that have revolutionized research methods. It plays an all-important part in industry. It has replaced steam as a source of power for our great factories. It refines and welds and plates metals. It runs big refrigerating plants. Electric milking machines and many other electrically operated devices have lightened the farmer's tasks. Electricity serves medical science, too.

TRANSIENT AND INDIRECT USE

We do not use electrical energy directly in most of its applications. For example, when an electric motor turns the shaft of a clothes washer, electrical energy is converted into mechanical energy. It is this mechanical energy that keeps tumbling our clothes about, bringing each article in contact with the water that flows into the machine and the detergents that are added to the water. When we turn on an electric lamp, electric energy heats a tungsten filament in the lamp until it glows brightly. Electric energy has been transformed into heat energy, and this in turn into light energy.

The electricity that operates a washing machine or a lamp is generated in a plant some distance away, at the instant it is needed to turn the shaft of the machine or to heat the filament of the lamp. At this plant electric generators are driven by turbines or internal-combustion engines, thus converting mechanical energy into electrical energy. Actually, therefore, the electricity used in most appliances represents a transient form of energy. Immediately after it is generated it is transmitted at the speed of light to the equipment in which it is to be used and it is there transformed into some other kind of energy.

Ten jet engines are used to produce electric power at a generating facility. This plant in Middletown Ohio, is one of the few of its kind

WHAT IS AN ELECTRIC CURRENT?

To understand what an electric current is, let us consider the basic structure of a material, such as copper or aluminum, that is used to conduct electricity. This material is made up of atoms, each consisting of a tiny nucleus, around which a number of electrons revolve. Each of the electrons has a single negative charge. The nucleus of a stable atom has a number of positive electrical charges, equal to the number of electrons whirling about it. The electrical forces of attraction between the opposite charges keep the electrons in their orbits.

In a *conducting* material, such as copper or aluminum, the atoms are so closely packed that they easily exchange their outer-orbit electrons, thus producing the effect of free electrons drifting in all directions through the metal. Ordinarily these free electrons distribute themselves evenly throughout a conductor, so that it is electrically neutral.

When a magnetic field is moved across a length of conducting material and at right angles to it, the free electrons are forced to one end of the conductor, giving that end a net negative electrical charge. The atoms at the opposite end of the conductor will then be deficient in electrons, giving a net positive electric charge. We could produce the same effect by moving the conducting material through the magnetic field.

The moment the magnetic field stops sweeping across the conductor or the conductor stops moving through the magnetic field, the force that had piled up the free electrons disappears. The electrical forces of attraction between the negative electrons at one end and the positively charged atoms at the other pull free electrons back to an even distribution along the conductor, which then again becomes electrically neutral.

The difference in electrical charge at the two ends of a conductor is called the *electrical potential,* or the *voltage.* The faster a conductor and magnetic field move with respect to one another, the higher the voltage induced in the conductor—that is, the greater the number of free electrons piled up at the negative end.

PRODUCING ELECTRIC CURRENT

Suppose now, that the ends of a generating conductor—one that is swept by a magnetic field—are connected by an outside loop of conducting wire. The electron-deficient atoms at the positive end of the generating conductor will tear away electrons from the atoms at the end of the outside circuit. These atoms in turn will seize electrons from the atoms next in line in the outside loop. This effect will extend all the way back to the negative end of the generating conductor. The outside loop atoms adjacent to this end will replenish their losses from the free electrons that have been heaped up through the action of the moving magnetic field.

In the meantime the atoms at the positive end of the generating conductor have been stripped of their newly acquired electrons by the moving magnetic field. They will again despoil their neighbors in the outside loop and these will seize electrons from their neighbors in turn. Electrons will continue to be passed on in this way from one atom to another as long as the conductor and the magnetic field keep moving with respect to one another. No individual electron moves through a circuit with great the speed of light—roughly 300,000 kilohopping from atom to atom "moves" with the speed of light—roughly, 300,000 kilometers per second. Somewhat the same effect could be produced by standing up a row of dominoes on end, each domino being close to the next one, and then tipping over the end domino. This domino would tip over its immediate neighbor, the neighbor would tip over the domino next in line and so on. No one domino would move far, but the "tipping effect" would move through the row of dominoes with considerable speed.

The cascading flow of electrons is what we call an *electric current.* The device that is used to produce the current in this particular instance is a very simple form of electric *generator.*

There are other ways of generating electric current. In the *dry cell,* current is made to flow through an electrolyte,

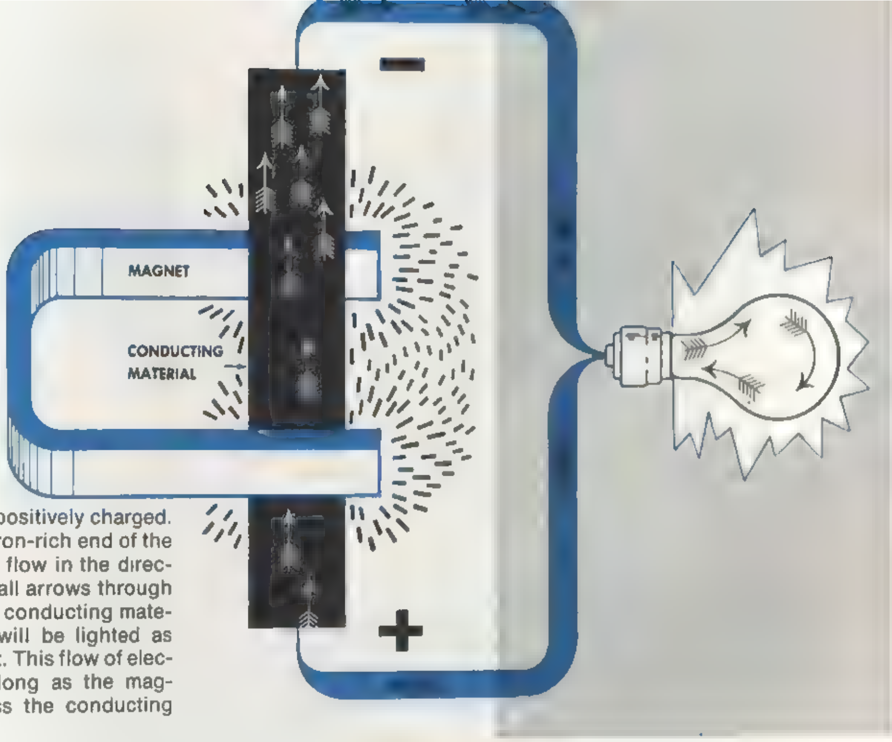


Diagram showing how electric current can be generated. As a magnetic field moves across a conducting material and at right angles to it, free electrons pile up at one end, giving a negative charge. The other end will be deficient in electrons and will be positively charged. Electrons from the electron-rich end of the conducting material will flow in the direction indicated by the small arrows through the wire and back to the conducting material. The electric lamp will be lighted as electrons pass through it. This flow of electrons will continue as long as the magnetic field moves across the conducting material

electrodes, and an external circuit, because there is a continuing chemical reaction between the electrodes and the electrolyte. The *storage battery* is based on the same principle. Current is also produced when light falls on certain materials, such as selenium and cesium, set in a glass bulb that is evacuated or filled with an inert gas. This device is known as a *photoelectric cell*. When two unlike metals, such as copper and iron or antimony and bismuth, are arranged so as to form a circuit and are then heated, current will flow through the circuit. The dissimilar metals form what is called a *thermoelectric couple*. The current generated by these devices would be altogether too feeble to run modern electric-supply systems. Such systems use electric generators exclusively.

GENERATORS

Most electric-generating stations have two or more generators of the *alternating-current* type. The magnetic field is produced by current-carrying wires coiled around soft iron cores. The assembly of coils and cores, known as the *field*, is mounted on a shaft. When this rotates, the magnetic field sweeps across the generating conductors, which are mounted on a stationary armature.

In alternating-current generators, the electrons regularly reverse their direction of flow. Starting in one direction, current builds up to a maximum and then subsides to zero. It then builds up to a maximum in the opposite direction and again diminishes to zero. This sequence is called a *cycle*. The standard frequency in the United States and most parts of Canada is 60 cycles a second, or 60 hertz. It is 50 cycles a second, or 50 hertz, in some European countries.

The generators have three sets of conductors, each developing the same voltage but differing in phase. This means that the peak voltages for the different sets of conductors are not developed at the same time, but follow each other according to a definite sequence. Generators of this type are known as three-phase generators. They ordinarily have three cables connected to outside electrical circuits.

ENERGY SOURCES FOR GENERATORS

In any electric generator, as we have seen, a shaft must be rotated in order to

cause a generating conductor and a magnetic field to move with respect to one another and thus to produce the flow of current. Various types of engines are used for this purpose. Each converts into mechanical energy some other type of energy, such as the chemical energy stored in fuels, or the kinetic energy of falling water, or the heat energy derived from the sun.

The conventional fuels commonly used today for the machines that drive electric generators are coal, lignite, oil, natural gas, wood, and waste products. They all contain chemical energy in a dormant or stored form. When they react with oxygen under high-temperature conditions, thermal energy, or heat energy, is released.

Nuclear fuels, such as uranium, plutonium, and thorium, are beginning to supplement the more conventional fuels that we have listed. The atoms in these fuels are split in a nuclear reactor and give off intense heat.

In the sunnier parts of the world, heat is generated by solar engines, as the sun's radiant energy is concentrated by mirrors or absorbed by large, dark-colored panels.

Some of the electrical energy generated in the United States comes from hydroelectric plants. Here the force of moving water produces electricity by turning the shafts of electric generators. The water is usually dammed first and then released through pipes against turbine wheels connected to generators.

A modification of this idea is used in some parts of the world to harness the natural tides of the ocean. Special basins trap the waters pushed into bays and harbors during flood tides and let them drain out through special pipelines as the tide recedes. The kinetic energy released as water shoots out from these pipelines can be used to drive electric generators.

TYPES OF GENERATING PLANTS

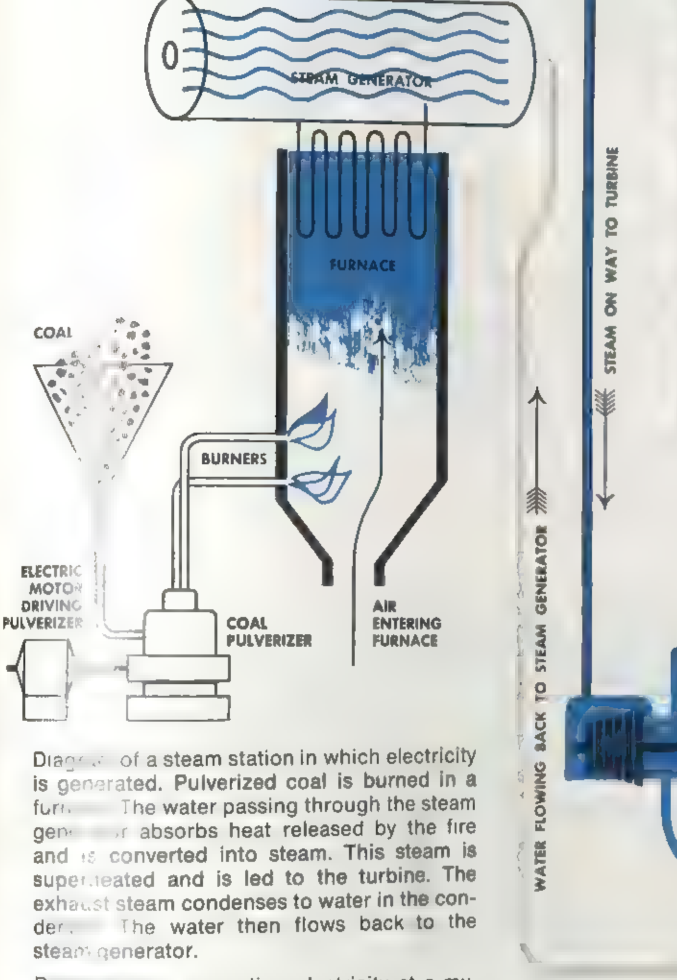
Steam stations. Most of the electrical energy used today is generated in steam stations, in which heat energy is converted into the mechanical energy required to turn the shafts of electric generators. Steam stations can run on any of the chemical fuels. In fact, they can utilize any energy source that produces heat. The heat is used to convert water into steam.

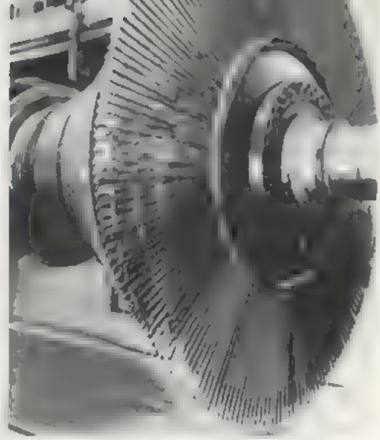
Pumps force water under high pressure into the steam generator, a complicated vessel made up of drums and tubes. As water passes through the generator, it absorbs the heat released by the fire of the burning fuel and is converted into steam. Before it leaves the generator the steam is led through another set of tubes exposed to the hot gases of the fire, and its temperature is raised to as much as 590° Celsius.

The superheated steam is now led to a steam turbine. It flows at high velocity past control valves and through nozzles. The steam jets that leave the nozzles strike blades mounted on the rims of wheels, or disks, and cause the disks to turn rapidly. As many as twenty turbine disks may be mounted in series—that is, one behind the other—on a single shaft. As the shaft turns, it drives the electric generator and produces current.

The flow of fuel and air to the steam-generator furnace is regulated by an automatic control system to match the fluctuations in the demand for electricity. When the demand for electricity increases, the turbine slows down. Its governor an automatic attachment for controlling speeds, then opens the control valves wider, thus admitting additional steam and restoring the set speed, which is either 1,800 or 3,600 revolutions per minute. When the steam valves are wide open, the increased steam flow from the steam generator causes the steam pressure in the generator to drop. This brings the combustion-control system into action. More air and fuel now flow into the furnace. This supplies more heat energy. The steam pressure is then restored to normal.

When the demand for electrical energy decreases, the generator shaft speeds up. The increasing speed causes the turbine governor to reduce the opening of the inlet steam valves and to reduce the steam flow. This restores the set generator speed. Reduced steam flow backs up the steam coming from the steam generator, causing the steam pressure to rise. The combustion





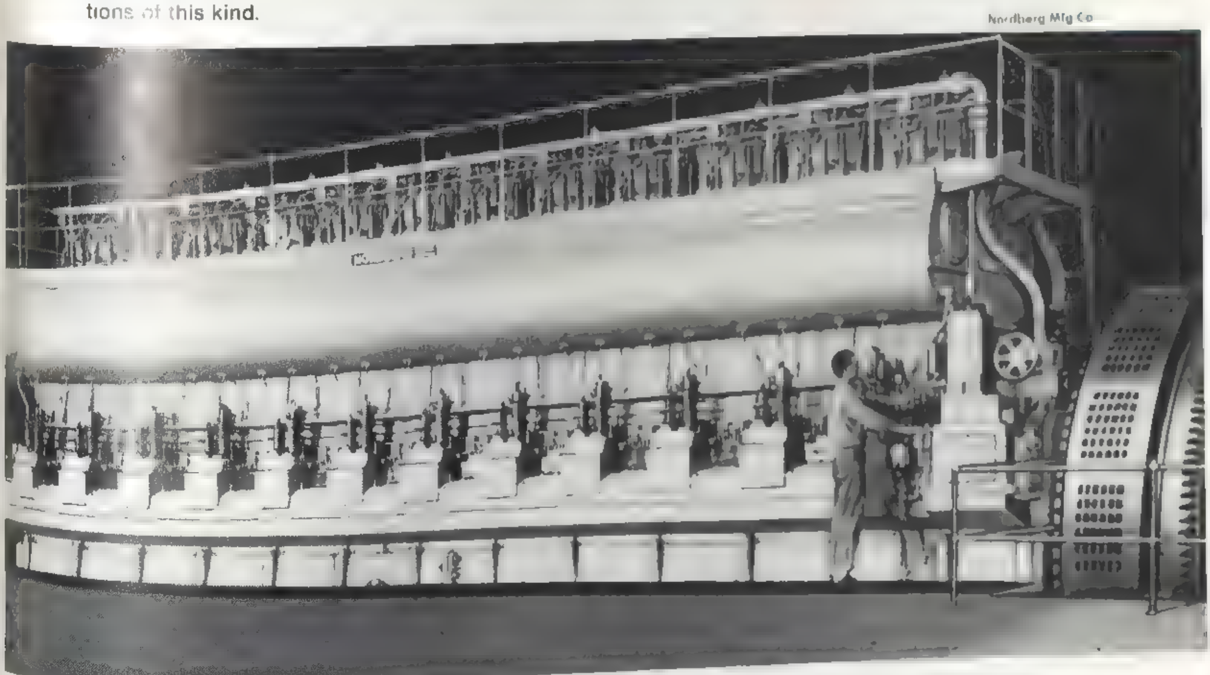
Babcock and Wilcox Co

Wheel and shaft of a giant steam turbine in the assembly stage. The wheel, called a rotor, will make 1,800 revolutions per minute as steam rushes through its blades.

Diagram of a steam station in which electricity is generated. Pulverized coal is burned in a furnace. The water passing through the steam generator absorbs heat released by the fire and is converted into steam. This steam is superheated and is led to the turbine. The exhaust steam condenses to water in the condenser. The water then flows back to the steam generator.

Diesel engine generating electricity at a municipal power plant. There are many installations of this kind.

Nordberg Mfg Co



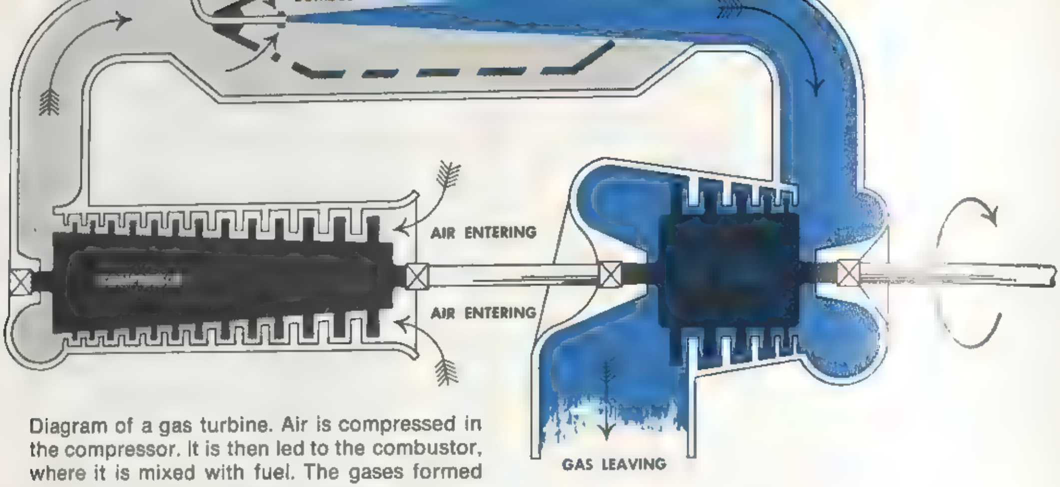
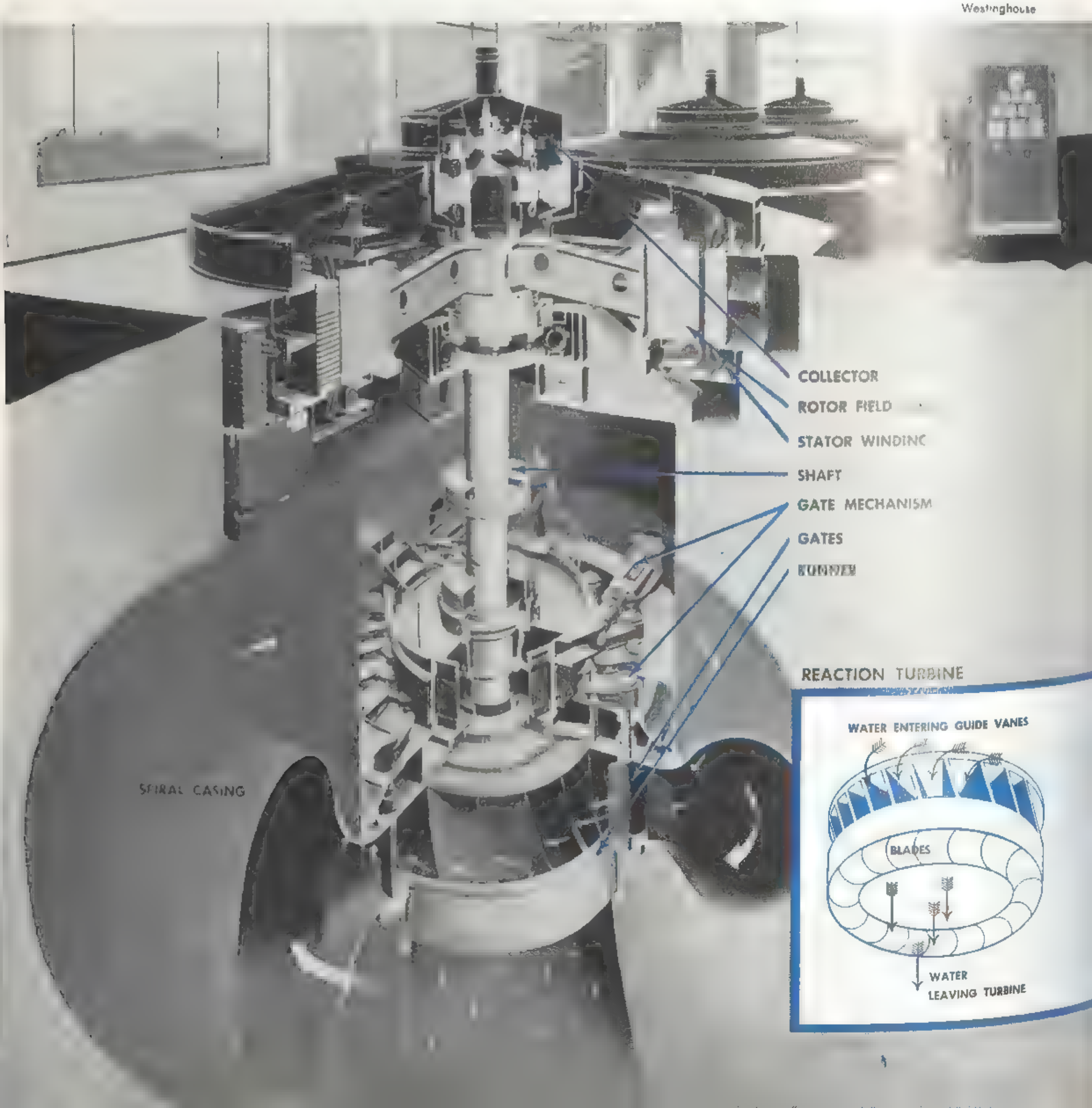


Diagram of a gas turbine. Air is compressed in the compressor. It is then led to the combustor, where it is mixed with fuel. The gases formed during combustion cause the blades of the turbine to turn

Westinghouse



control system then reduces the flow of fuel and air into the furnace. Steam pressure is now brought back to normal.

Nuclear-powered stations. About the only difference between conventional steam stations and nuclear-powered stations lies in the way heat is generated. Instead of a steam generator, provided with a furnace to burn chemical fuels, the nuclear plant has a reactor that holds the fuel—uranium, plutonium, or thorium—in a core arranged in a fixed pattern. When the fuel is allowed to fission in a controlled chain reaction, heat is generated and applied to a fluid, such as high-pressure water or liquid metal, circulating in a closed system. The heated fluid converts water circulating in another closed system into steam, and the steam runs a turbine.

A nuclear-power plant may be able to run a year or more on a single fuel charge. The heat production depends on the rate of fissioning. This can be varied by moving control rods in and out of the core. Thus the nuclear power plant can meet the fluctuating demands for electric energy.

Plants with diesel engines. Internal-combustion engines used to generate electricity in power plants are usually of the diesel type. After an engine cylinder takes in a fresh charge of air, a piston compresses the air to about $1/17$ of its original volume and causes it to be heated. A special pump injects a small amount of fuel into this hot air. The air-fuel mixture ignites and immediately burns. The burning fuel generates hot gases, which exert tremendous force on the piston. This force pushes the piston down and makes it turn a crankshaft that drives the electric generator. At the end of the stroke a valve opens to release the spent gas to the outer air. The cylinder takes in a fresh charge of air, in order to compress it and repeat the cycle. An engine like this, in which a piston moves to and fro in a cylinder, is called a *reciprocating engine*.

The amount of fuel injected into the cylinders of an engine must be regulated to vary with the demand for electrical energy. The control system works directly from the speed of the engine shaft. As the demand for electric energy rises, the shaft tends to slow down. This makes the control system inject more fuel into the cylinders. As more fuel is burned, the force acting on the pistons is increased and the engine speed is brought back to standard. When the demand for electric energy drops, the engine shaft speeds up. The control system reduces the amount of fuel injected to reduce the piston force, and the engine speed is correspondingly reduced.

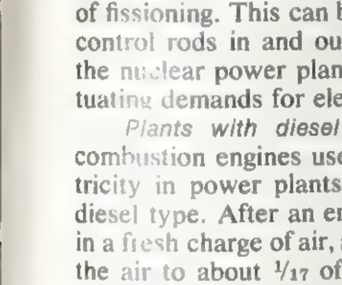
There are more internal-combustion-engine stations of this kind in the United States than any other types of generating stations. However, these plants are relatively small and account for only a slight percentage of the total electric generating capacity.

Gas-turbine plants. The gas turbine is an internal-combustion engine, like the diesel engine. However, it depends on a continuous flow of air and fuel through the engine instead of a rapid intermittent flow, as in the reciprocating engine.

The simple gas turbine has three main elements: a compressor, a combustion chamber, and a turbine. The turbine works on the same basic principles as the steam turbine, but jets of hot combustion gases, instead of steam jets, are used to exert force on the turbine blades. The turbine drives the compressor and the electric generator, both mounted on a common shaft.

The compressor has the same arrangement as a turbine. Blades mounted on disks ride on the rotating shaft and there are stationary nozzles between rows of blades. The whirling blades take in air from the atmosphere in continuous "bites," like a

IMPULSE TURBINE



Far left: a hydroelectric station. Water strikes the turbine blades, turns a shaft, and drives the connected generator above the turbine. The smaller drawings show two types of water turbines—the Francis reaction turbine and the impulse turbine (Pelton water wheel).

rotating fan, and force it through the nozzles to compress it to a higher pressure. This is done from ten to twenty times in series. The air pressure is raised to as much as 22 kilograms per square centimeter.

The pressurized air flows in a continuous stream into a combustion chamber. Here it is mixed with atomized oil or gas and burns. The gases of combustion leave the chamber at temperatures as high as 815° Celsius. They then enter the first-stage nozzles of the turbine. In passing through the different series of nozzles and blades, the combustion gases expand, with a resulting lowering of pressure. They leave the turbine at atmospheric pressure with a temperature of about 480° Celsius. The hot exhaust is led to the outer air in some engines. In more efficient gas turbines, this exhaust is led through a heat exchanger, called a *regenerator*, and passes over the surface of many tubes before being discharged to the atmosphere. The pressurized air leaving the compressor passes through these tubes and is heated before it enters the combustion chamber. This results in considerable savings in fuel.

A control system based upon shaft speed varies the fuel flow to meet fluctuations in the demand for electricity. The air flow in the simple gas turbine remains constant at all loads. In more advanced designs there are two turbines in series. One drives only the compressor, the other one only the electric generator. In this arrangement the air flow also varies with the electric load.

Hydroelectric-power stations. The stations that use the force of running water to generate electricity tap a gigantic energy cycle powered by the sun. As the sun's rays warm our planet, water evaporates from oceans, lakes, rivers, the ground, and the aerial parts of plants and enters the atmosphere as water vapor. Later, the vapor condenses and forms clouds or mist. When precipitation takes place in the form of rain, snow, hail, and so on, part of the water falls in the ocean. Much of the water that falls on the land makes its way to the sea in the form of surface streams. It is at this stage that the water cycle yields up some of its energy (a very small part)

Hydroelectric power is obtained by allowing a swift-moving river to run a turbine. Here a view of the Chickamauga Dam in Tennessee, part of a large hydroelectric station in the United States.

to operate hydroelectric stations. As a river drops sharply, it is made to convert its pressure energy into mechanical shaft power. This is used to drive an electric generator.

Two conditions are necessary to supply power for a hydroelectric station (often called simply a hydro station). These are the actual amount of water used, or flow, and an adequate *head*, or water pressure. The head depends upon the actual height of the column of water above the hydro station. These two conditions may be combined in any proportion. For instance, the amount of water used at one plant may be large but the pressure small (due to a small drop in elevation). At another plant of equal capacity the water used may be relatively little but the water pressure great.

When the lay of the land is favorable, an increase in water elevation can be caused by building a dam across a river. This causes the water to accumulate, providing a large flow, and piles it up to a higher elevation. A pipeline, or penstock, pierces the bottom of the dam and leads the water to turbines in the powerhouse, which is at the dam. The turbines are set at the lowest possible elevation to wring the maximum amount of energy out of the water. After passing through the turbines the spent wa-

Tennessee Valley Authority

ter returns to the river and continues its journey to the ocean.

In some places the water of mountain streams is impounded behind a dam at a height of as much as 1,500 meters above the generating plant. The relatively small amount of water is then led down the mountainside in a penstock to the turbine of the powerhouse. In this case the water, having a very large head, is made to turn an impulse turbine.

Water turbines may be divided into two main groups—impulse and reaction. The simplified diagram of an impulse turbine (the Pelton water wheel) is shown on page 389. A series of buckets is mounted on the rim of a wheel. A jet of water issues at high velocity from a nozzle, strikes each of the buckets in turn, and causes the wheel to rotate. The axle of the wheel is connected to the shaft of the electric generator.

The reaction turbine is based on a different principle. The Francis reaction turbine is shown on page 388. The shaft may be either horizontal or vertical. A series of blades is mounted on the turning element, or runner, of this water wheel. Water is admitted through a series of fixed guide vanes and strikes all the blades simultaneously. When the water enters through the guide vanes, the direction of its flow is at right angles to the shaft of the turbine. The flow is then deflected until it leaves the runner nearly parallel to the shaft. This change in direction causes the water to exert great

Electricity must be distributed after it is generated. High-voltage transmission lines such as these carry large amounts of power over long distances.

force on the blades, turning the shaft and driving the connected generator shaft. The Kaplan reaction turbine has movable blades. The pitch of these blades can be changed so that the water will always hit them with the maximum force, regardless of changes in load.

Water flow through the turbines must be regulated to match the fluctuating demand for electric energy. An automatic control does this by opening or closing control valves at the turbine-water inlet in response to changes in shaft speed.

In most areas river flow is high in late winter and early spring and very low in late summer and early fall. Where the lay of the land permits, dams may be built to store water, which can be drawn upon as needed during low-flow periods.

The dams that impound water for certain hydro stations have small storage capacity. They serve rather to create a "head" of water than to store up any appreciable quantity. Plants of this kind are

called "run-of-river." They take the water as it comes and generate as much electricity as they can. An arrangement of this kind is very useful when the maximum river flow coincides with the maximum or peak demand for electricity.

Most modern power systems use a combination of hydro and thermal stations. When the river flow is high, the hydro plants generate as much electricity as possible in order to save the fuel that is necessary for operation of thermal stations when river flow is low.

LEAVING THE GENERATOR

If current could be led to transmission lines direct from the generators, electric generating stations would not be nearly as complicated as they are. Actually the current leaving the generator travels through several devices before it is sent humming through the transmission lines. For one thing, elaborate precautions have to be taken against potentially dangerous short circuits. A *short circuit* is brought about when a short cut is provided for the current flowing through a circuit, so that resistance to the passage of the electricity is greatly reduced. As a result, the current builds up to a dangerous level.

One way of guarding against short circuits is to provide adequate *insulation* for cables or for the supports of conductors. Insulating materials have atoms that hold their electrons tightly. They have practically no free electrons. Therefore, when magnetic fields sweep across them, no electric currents are induced. When insulating materials closely surround a conductor or support it, the electron-deficient atoms of the conductor cannot tear many electrons from the atoms of the insulator. Insulation is always a matter of degree. No insulation is so perfect that absolutely no current can pass through it.

It is not enough to ensure adequate insulation. It is also necessary to provide methods for instantly shutting down parts of the system subjected to short circuits. This is made possible by *circuit breakers*—switches that automatically open when abnormal conditions arise, thus disconnecting a generator or transmission line from the system. Disconnecting switches are placed on either side of a circuit breaker. They are opened only when the breaker is open and carrying no current. They serve to insure that no voltage will be applied to the breaker while it is being inspected or repaired by plant personnel. The increasing current that surges through cables under abnormal conditions can be limited or choked by reactors, which are cables wound into a spiral (helix) of a few turns.

TRANSFORMERS

Besides providing ample protection against short circuits, electric generating stations must also pass current through step-up transformers in order to increase the voltage. To explain why this is desirable, we must point out that electric power has two components: voltage, or electromotive force, and *amperage*, or current flow. A given power can be transmitted with varying proportions of voltage and amperage. A low voltage can drive a high current, and high voltage, a low current.

A cable must have a large diameter to carry a high current driven by a low voltage. The diameter is much smaller if the cable carries a low current driven by high voltage. To economize on conducting materials, electricity is usually generated and distributed at as high voltages as feasible. Many modern generators run at from 11,000 to 18,000 volts. Before the power leaves the station, its potential may be stepped up to 345,000 volts or even more.

Transformers can be used only on alternating-current systems. They have no moving parts. Generally they consist of two windings of wire on a common core. One winding is connected to the generator; this is the primary coil. The other is connected to the outgoing transmission line; this is the secondary coil. The alternating current, passing through the winding connected to the generator, creates an alternating magnetic field in the core. This field grows and then collapses as the current moves in one direction. It grows and collapses again as the current moves in the opposite direction. As the magnetic field moves over the sec-

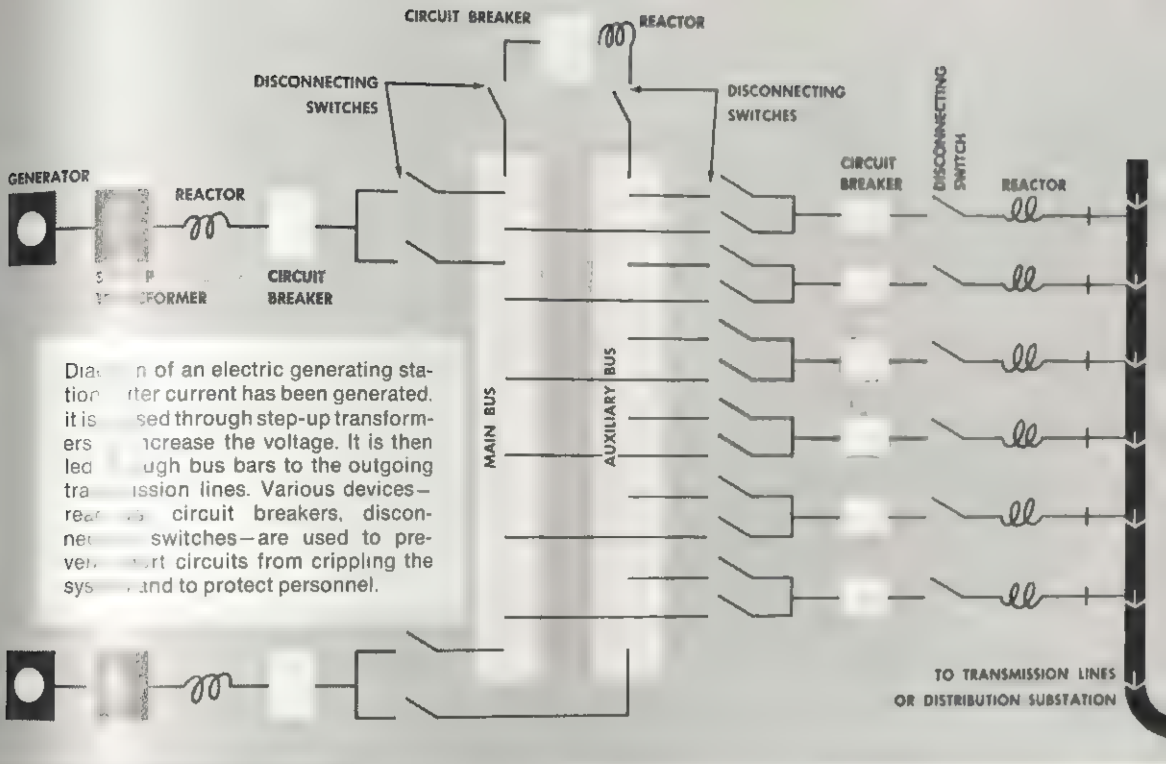


Diagram of an electric generating station. After current has been generated, it is passed through step-up transformers to increase the voltage. It is then led through bus bars to the outgoing transmission lines. Various devices—reactors, circuit breakers, disconnecting switches—are used to prevent short circuits from crippling the system and to protect personnel.

ondary coil, it generates an alternating voltage in it. The greater the number of turns in this coil, the higher the voltage induced. The current will vary inversely with voltage. For example, if the voltage is stepped up fifteen times, the current will be reduced to a fifteenth of its former value.

Buses, or bus bars, play an important part in electric generating stations. A bus is a conductor that serves as a common connection for several circuits. It is made of heavy copper and is supported on insulators.

The electric generators of a given station are connected to the outgoing transmission lines through the different devices that we have just described—circuit breakers, disconnecting switches, reactors, transformers, and buses. The exact sequence of these different items of equipment varies in different stations.

TRANSMISSION LINES

Transmission lines leading from generator stations generally run at potentials higher than 60,000 volts. As we have pointed out, the voltage may be in the hundreds of thousands. Transmission systems differ considerably in design. An outstanding feature of all of them is the series of tall poles or towers, of steel or wood, that carry the copper or aluminum conductors. These conductors are seldom insulated. Instead, the bare wires are strung from tower to tower high up in the air and far enough away from one another to prevent short circuiting through the air. Ceramic insulators keep these conductors from actual contact with the towers.

The conductors must be strung tight to prevent excessive sagging and swinging. The towers and poles must be strong enough to stand the pull of the conductors. They must also be able to withstand wind pressure and to carry any additional weight that may be imposed upon them by accumulations of snow or ice.

Since transmission lines usually run through open country and often over mountain tops, they are vulnerable to lightning strokes. To lead off such high-voltage strokes, ground lines are provided. They are strung from tower to tower at the topmost point. At each tower a heavy cable leads from the ground line to a grid of conductors buried in the earth at the foot of the

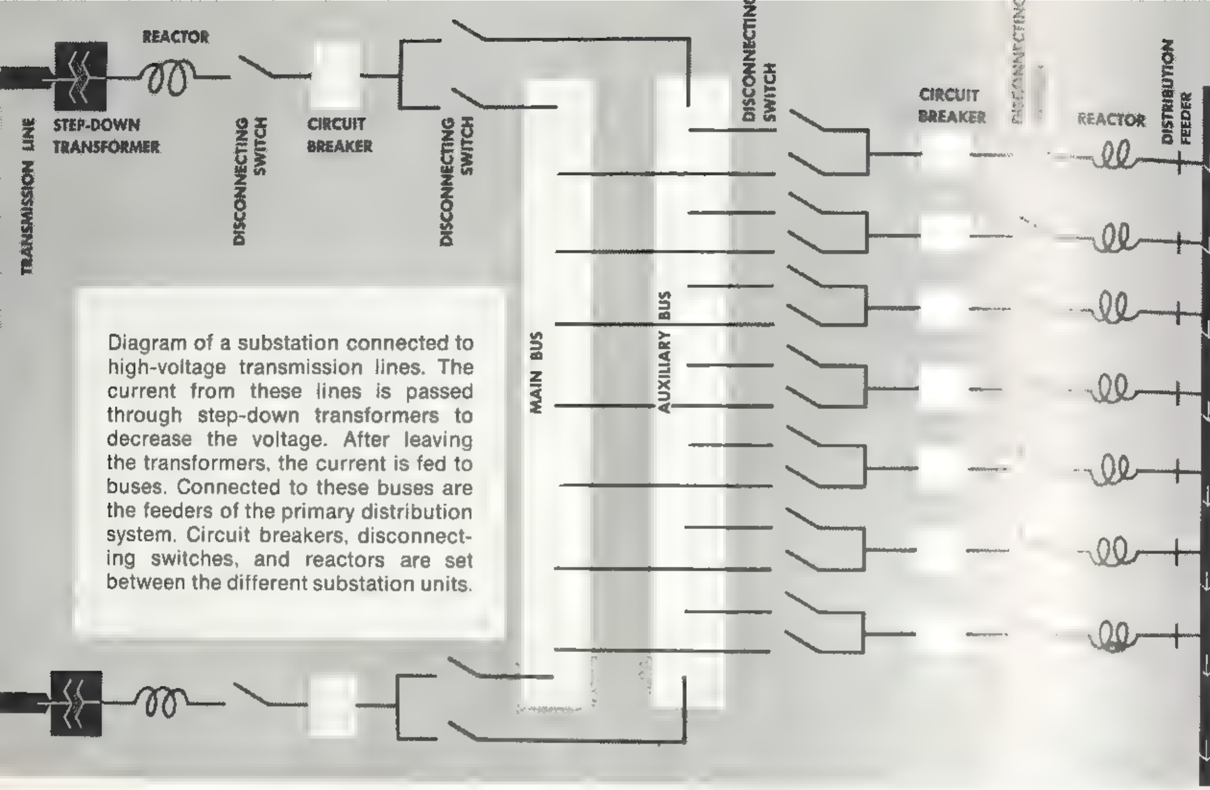


Diagram of a substation connected to high-voltage transmission lines. The current from these lines is passed through step-down transformers to decrease the voltage. After leaving the transformers, the current is fed to buses. Connected to these buses are the feeders of the primary distribution system. Circuit breakers, disconnecting switches, and reactors are set between the different substation units.

tower. Lightning arresters, which carry lightning discharges from the conductors to the ground, are set at the supporting insulators of the main conducting lines.

In urban areas transmission lines may be installed underground. Generally solid insulation is used for the cables. Cables are protected by a lead sheath or a metal pipe. Sometimes insulation consists of oil or gas. The cables are snaked through ducts running between manholes, which are spaced from 100 to 1,200 meters apart.

Transmission lines tie together generating stations many kilometers apart. As a result, the modern electric system, consisting of generating stations, transmission systems, and distribution systems, can be run as a network with a great deal of flexibility and with ample insurance against frequent accidental interruption of service.

DISTRIBUTION SYSTEMS

A distribution system takes electric energy from a transmission line or directly from a station bus. It first reduces the voltage to a level considered safe for distribution through city streets—primary distribution system. Later, it reduces the voltage to the much lower level at which electrical devices operate. This is the secondary distribution system.

The distribution system starts with a *substation* connected to a transmission line or station bus. Some large factories have their own substations because of the large amount of power that they use. On this page we show a simplified diagram of a substation. The cables of this station lead from transmission lines to a high-voltage bus. Connected to this bus are several step-down transformers. After leaving these transformers the current is led to a low-voltage bus. The feeders of the primary distribution system are connected to this bus. Primary-system voltages may range up to 13,800 volts. Generally, however, systems feeding domestic and commercial loads run at 2,400 to 4,800 volts.

Primary Distribution System. The wires of the primary system may be supported on poles or laid underground through a system of manholes and ducts. The method to be used will depend on various factors: load density, continuity of service, the congestion of wires on poles, the need for installing large transformers on every pole, the

difficulty of mounting these transformers, operation and maintenance difficulties, and the appearance of the street through which the wires run.

The primary distribution circuits may be of the radial or network type. In a radial system, a feeder leaves the substation and is tapped off at intervals to serve various lateral, or side, branches. In the network type, the primary circuit is supplied through two or more feeders from two or more transformers or bus sections in the substation. Since there are several feeder lines, service may not be interrupted at all if a short circuit takes place in one of the lines. Under similar conditions service on a radial type of circuit might be interrupted beyond the short circuit, or the whole line might go dead.

Secondary Distribution System. The secondary circuits of the distributing system are fed from step-down transformers tapped on the primary-system circuits. The voltages of secondary circuits range from 120 for domestic supply to as high as 600 for industrial and commercial customers. The wires in such circuits may be either overhead or underground. The circuits may be of the radial or network types.

WIRES

Wires for primary and secondary distribution service usually have a solid insulation covering. In underground systems they are usually protected by an outer sheath of lead. Overhead wires are supported on porcelain insulators held by the pole crossarms. Circuit breakers or fuses, or both, may be installed at intervals in primary and secondary circuits to protect them against overloads or accidental short circuits. *Reclosers* are being used increasingly. These are circuit breakers that automatically reclose after opening.

Customer's *leads*—wires leading to various buildings—tap the secondary circuits at a convenient point. For an overhead system, this would be the nearest pole. The current flows through wires extending from the pole to the customer's building. They then pass through a metal conduit and to the customer's meter and fuse box.

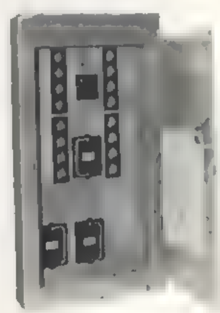
In the case of an underground system, the customer's lead taps the circuit at the nearest connection box or manhole. The current leads from this point go through a duct to the customer's building. The duct may pierce the basement wall, or it may be taken up through the surface of the ground and led to some other point on the outside of the building. The wires in the duct are then led to the appropriate meter and fuse box.

The *watt-hour meter* measures the amount of electric power used by a consumer. It has a special kind of motor, with an armature consisting of a rotating coil. The armature turns with a speed relative to the amount of electric energy flowing through the meter. This amount is indicated on a dial in *kilowatt-hours*. A *kilowatt* is a thousand watts. A kilowatt-hour is the electrical energy consumed in one hour at the constant rate of one kilowatt.

Left: a transformer mounted on the pole of a distribution system. From here the current flows to a watt-hour meter (center) and from the meter to a fuse box (right), through which several circuits run.

General Electric

Long Island Lighting Co



Edison Electric Institute

New substation facilities are designed with the latest equipment to provide reliable service.

Electric Institute

Electricity serves the transportation industry. Here a modern train runs on electrified rails.

From the meter the wires run to a fuse box or distribution box. Four or more circuits, tapped off the main wires and protected by fuses or circuit breakers, may feed several electrical devices each. Each one of these devices has its own switch, so that it may be connected to the feed circuit or disconnected from it. Electric wires in a building may run through metal conduits to outlet boxes, where individual electrical devices may tap in. In some industrial plants the wires, which are heavy, insulated cables, are simply laid in open trays.

MODERN USES OF ELECTRICITY

Thus electricity is transmitted from generating stations to factories, places of business, and homes. We have already mentioned a few of the uses to which it is put. Here is a rapid survey of some of the important fields in which it serves man.

Lighting. The incandescent filament lamp, the arc lamp, the mercury-arc lamp, and the fluorescent lamp are all based on the use of electricity. Current flows through the filament of the incandescent lamp and heats it until it glows. In the arc lamp, an arc is produced between two electrodes and one of these electrodes becomes white hot. In some cases, the arc itself provides light. Electric current vaporizes mercury in mercury-arc lamps and causes it to luminesce. In fluorescent lamps a mercury-vapor arc produces radiation (primarily ultraviolet). This causes a phosphor coating on the lamp to glow.

Heating. When electricity flows through any resistance, it dissipates a part of its energy as heat. This is called *resistance heating*. There are various applications of this principle in the home. We find it in electric ranges and heaters, therapeutic lamps, toasters, percolators, waffle irons, rotisseries, skillets, and clothes dryers. Industrial applications include ovens, kilns, sterilizers, and boilers.

There are various other types of electric heating devices. In *dielectric heating*, the material that is to be heat treated is placed between two plates. Voltage across the plates may run as high as 15,000 volts. Frequencies may come to as much as 30,000,000 hertz. In *induction heating*, the alternating current passes through a coil surrounding the material that is to be heated. This induces a current in the material, which becomes hot because of its resistance to the current. Electric furnaces in which metals are melted depend on the electric arc to produce heat.

Communication. The telegraph and telephone and such electronic devices as radio, television, and radar are all based on electricity. The telegraph and telephone work on low voltages and currents. High voltages and low currents are required for the electronic devices we have mentioned. Low-voltage, low-current, high-frequency circuits are used in public-address systems.

Electric utilities use a special type of communication system known as *carrier current*. It resembles radio in many respects. However, the high-frequency, low-current waves are carried over power transmission lines between stations and substations instead of through the air. The carrier current system is used for voice communication, transmission of instrument readings, and relay operation. It makes it possible to run substations and hydro stations by remote control.

Shaft power. One of the most important uses of electricity is to provide shaft power by means of electric motors. There is a bewildering variety of such motors, which range from tiny devices with a capacity of less than a hundredth of one horsepower to huge machines with a horsepower rating in the tens of thousands. At least two dozen motors are used in the home. They power clothes washers, dish washers, clothes dryers, oil burners, food mixers, meat cutters, sharpeners, ventilating and circulating fans, refrigerators, clocks, vacuum cleaners, ironers, air conditioners, motion-picture projectors, phonographs, tape recorders, dry shavers, massagers, and other devices.

Motors play a supremely important part in industry. They run pumps, compressors, blowers, machine tools, woodworking machines, hoists, conveyers, cranes, unloaders, excavators, printing presses, and many other devices. They are used extensively in mills where paper, steel, textiles, flour, cement, and many other products are manufactured.

The motors of certain vehicles, such as subway trains, trolley buses, street cars, and electric locomotives, are run by the electricity produced in generating stations. In other cases, as we have pointed out, vehicles and ships generate their own electric power.

Electrometallurgy. Electric current is used widely in electroplating, in which the surface of a metal is covered with a thin coating of another metal. The object to be plated is made the cathode of an electrolytic cell. The anode is composed of the metal that is to be deposited. A salt of the same metal forms part of the electrolyte. Electric current, passing through the electrolyte, dissolves as much material from the anode as is deposited on the cathode. Plating is widely used for protecting metallic surfaces or for decoration, or for both.

Electric current also serves in the refining of aluminum, calcium, beryllium, magnesium, and other metals. As in electroplating, the process is based on electrolysis—chemical decomposition by the action of an electric current.

Electronics. Electronics is one of the important applications of electricity. It is concerned primarily with the conduction of electricity through gases and vacuums and also through semiconductors, such as germanium and silicon. The basic electronic device is the transistor, now being supplemented with the electron tube.

We have already mentioned certain electronic devices used for communication purposes: radio, television, and radar. In industry electronics provides instruments and machines that make many different kinds of measurements with great speed and accuracy. Electronic devices process and inspect materials, open doors, detect fumes, trigger burglar alarms, and protect workers against industrial hazards.

Medical uses. The medical applications of electricity have markedly advanced the treatment of disease and the techniques of diagnosis. Certain electric lamps produce ultraviolet rays, which can provide many of the beneficial effects of sunlight. Other lamps generate infrared rays, used in heat treatment. The heat produced by high-frequency currents in a diathermy apparatus penetrates deep within a patient's tissues. X rays, based on the use of electric current, are particularly valuable to medical science because they make it possible to see and photograph the interior of the human body. Various other devices operated by electricity have proved valuable to the diagnostician. Among these are the electrocardiograph, which records the electric impulses accompanying the beat of the heart, and the electroencephalograph, which examines the pattern of brain waves. These represent only a few of the applications of electricity to medicine.

Other applications. We have mentioned only the applications of the electricity produced in generating stations. A considerable number of devices (flashlights, hearing aids, small vacuum cleaners, and the like) obtain current from batteries. Certain vehicles generate their own current: the automobile and diesel-electric locomotive are good examples. Self-contained electric systems are also found in airplanes and ships.

ENVIRONMENTAL SCIENCES

Left: Grant Heilman
Above: UPI

The setting for our activities is called "The Environment." Of course, we share the environment with other living things. Dumping of now-useless items (left) affects the environment of plants, animals, and people living on the land. Careless handling of oil tankers can result in spills that severely damage the marine ecosystem.

CONSERVATION

by Peter Larkin

We inherit the earth from our parents and give it to our children. Believers in conservation—the saving of natural resources—feel obligated to pass on something better than they have received.

If you owned the world, what would you do with it? Would you cut down the forests, plow up the land, dam the rivers, and burn all the coal and oil? Would you plunder your own earth? Would you then let your children worry about any problems the future might bring?

Conservationists believe you must not squander your inheritance. They say: "Yes, use what the earth has to offer, but use it wisely. Use it in a way that thinks as much of tomorrow as it does of today."

Conservation is not only the wise use of your natural environmental inheritance, but more. You should not take everything, but should save much of it for the delight and beauty it may afford. Mountains, forests, rivers, lakes, and the living things that inhabit them, must be treasured for themselves and for the recreation they offer. And you must not pollute this noble inheritance.

EARLY IDEAS

Many basic conservation ideas were put into practice long before the dawn of written history. Ancient man often viewed the earth and its life as gods who had to be worshiped and cared for. Early hunters would or could not kill animals for pleasure. Many nomads—people wandering from place to place—moved their herds of animals, which thus did not overgraze the land. Prehistoric farmers realized that it was better for the land to lie fallow, or un-

A land's natural beauty and its recreational potential are precious resources that should be conserved, not squandered and perhaps lost forever

Finnish National Tourist Office

cultivated, from time to time. They added compost and manure as another way to restore the soil to its natural fertility. Those who did not learn these lessons eventually became reduced to poverty, and their cultures died out.

But mankind forgets and needs to be reeducated from time to time. The Greeks and the Romans, for example, despite their marvelous civilizations, did not always understand the land they occupied. By cutting down trees and raising too many sheep and goats on the plains and mountainsides around the eastern end of the Mediterranean Sea, they created a near-desert there.

Some authorities even believe the Sahara is a man-made desert. It may have been started by overgrazing of domesticated herds in ancient Africa. Later changes in climate ensured the continued expansion of the Sahara until it became as vast as you see it today. There have been plans to restore this wasteland with water from underground rocks or from the Mediterranean Sea, but they have not yet been put into effect.

From time to time, different people in different parts of the world discovered for themselves that they could not force the land beyond its natural capacity. Attempts to do so were ultimately disastrous.

IN THE TWENTIETH CENTURY

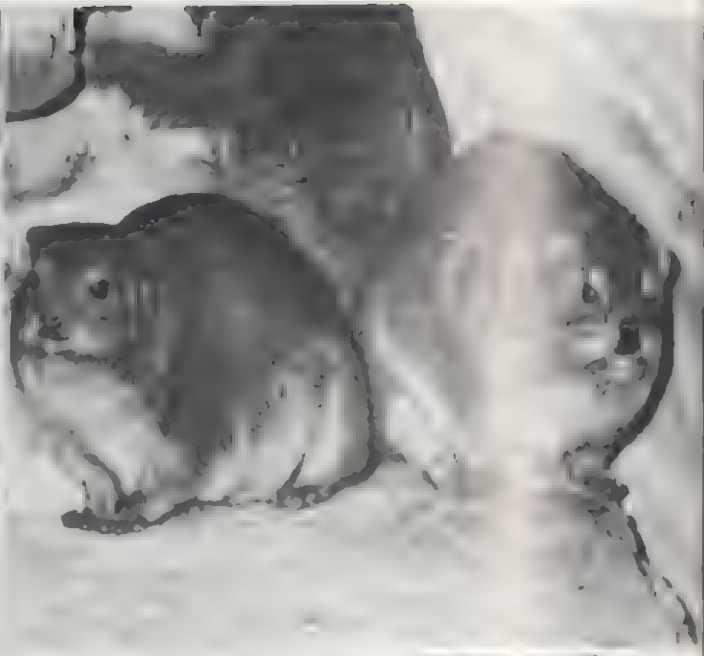
Conservation arose as a well-thought-out philosophy and an organized movement during the last years of the nineteenth century and the opening of the twentieth. The great technological advances and inventions of the preceding hundred years had prepared the way. They had brought vastly increased knowledge and power to humanity.

For example, steam power made it possible to cut down trees and plow the land on a far more ambitious scale than ever before. The development of reinforced concrete opened opportunities for building gigantic new dams. People of experience and vision could see that the wise use of these inventions would be critical for the future of civilization, for better and for worse. From such concern, the modern conservation movement had its birth.

During the industrial expansion in the early twentieth century, the conservationists' first aim was to preserve the natural

In the late 1800s, white hunters slaughtered the vast herds of buffalos that roamed the North American plains. Indians who depended on this food source were on the verge of starvation and performed dances for the herds' return

Courtesy of the American Museum of Natural History



wonders of the world for later generations to enjoy. In North America alone, for example, the passenger pigeon was already a thing of the past, and the buffalo were almost gone.

The very land also came to be threatened. In the development fever of the early 1900's, it seemed that every last parcel of land would be commercially exploited. Perhaps even the most beautiful natural features would soon be doomed to disappear under the onslaughts of explosives and steam shovels. Conservationists urged us to save these wonders as national treasures.

With broad public approval, the first steps were taken to rescue our environment. National parks were established in the United States. In Canada and Australia, a similar awakening of public opinion saved much land for parks. "Greenbelt" policies were adopted, keeping land from urban development and preserving it for nature or for farming. In Europe, too, the conservationist cause found its voice.

SAVE—FOR FUTURE USE

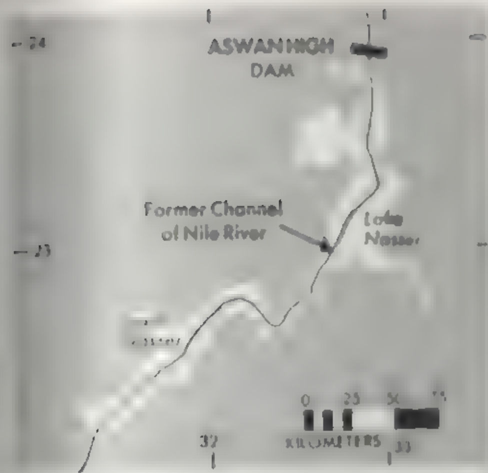
Soon more and more people began to realize that 20th-century technology was reaching every corner of the globe, to affect everyone and everything. It would often quickly exhaust the most productive land and sources of water, reducing them to ruin. Vast stretches of the earth's surface were actually gutted of their trees, soil, and minerals.

Conservationists then asked: "How can we keep our resources continuously producing the food, water, and materials we need?" Preached as "the gospel of efficiency," conservation aimed to show that we would be wise to ensure that our forests would always yield timber; our streams, water and fish; and our soil, bountiful crops.

Shortly afterward, the "gospel" began to bear fruit. Laws were passed protecting our environment. Fishing regulations were adopted for lakes, streams, and coastal areas.

Much of our present knowledge about caring for land, animals, vegetation, and water emerged during the years that followed the first burst of conservationist thinking. Almost everywhere, but particularly in North America, the technologies of agriculture, game management, fisheries, and water control were built around the theme of conservation of resources.

These moves were spurred by bitter experiences, such as soil erosion during the



Egypt's Aswan High Dam has seriously affected the ecology of the surrounding area. Nutrient-rich sediment that once flowed down the Nile River is now trapped in the lake forming behind the dam. The striped hyena (opposite page, far left) and the rock hyrax (near left) are two of the many species whose habitats have been adversely affected by the rising waters of Lake Nasser. However, other organisms, including some disease-bearing insects and snails, are thriving under the environmental conditions created by the dam.

drought years of the 1930's, vast forest fires, great floods, and the overfishing of the California sardine and the Atlantic salmon.

By 1950, there were many examples of both good and bad resources management along with conservationists' strong determination to do a better job in the future. There was also growing awareness that other human activities would soon bear closer examination by authorities.

One such activity was the pollution of rivers flowing past large cities. Chlorination of drinking water, to kill germs, was already a common public health precaution. But it was a matter of record that sewage and industrial wastes were making rivers unfit for many fish and unpleasant or dangerous for humans also. Equally obvious were the scars left on the land by strip or surface mining of coal, by placer or water-jet mining of gold, and by piled-up wastes of one kind or another.

Added to the growing burden of pollution and land damage is the continuing great increase in world population since 1950. Between 1950 and 1970, more people were born than in the half century from 1900 to 1950. There are now well over 4.4 billion people in the world, and the number increases by 75 million a year. By the year 2000, projections put the world population at 6.4 billion—nearly double the 1970 figure.

Moreover, each person has far more mechanical power with which to change his environment than any one of his predecessors. If you multiply the present population use by the new power, you get what may amount to a 30-times increase in human activity since 1900.

No wonder that in these circumstances we are bewildered by change and also suddenly aware of the many new possibilities in conservation. If there ever was a time for being conservation-minded, it is now. This thought applies not just to the wise management of resources [illegible] use in goods and services.

The milt being stripped from this male salmon will be used to fertilize eggs taken from a female in the controlled environment of a fish hatchery. Hatcheries are used to try to replenish populations [illegible]

Weyerhaeuser Company

The bands around the trunk of this tree are sensitive enough to record tree growth every half hour. Such information contributes to better forest management.

Also, we conserve natural resources when we reuse waste materials. That glass bottle, plastic container, metal can, or scrap paper you carelessly toss away could be recycled into another product.

RENEWABLE RESOURCES

Renewable resources are those that can be reused many times or, once used, can be restored or grown back in a reasonable period of time. Soil, water, forests, other vegetation, fish, and other animals are renewable resources. A given soil may yield numerous crops year after year. It can also be improved or restored with fertilizers. Water is replenished by rain or snow; or it may be piped in or recycled.

Living things renew themselves through reproduction. Their numbers are regulated by the rates at which they are born, live, reproduce, and die. As man takes and uses trees, crops, and animals, he is said to "harvest" them.

Whenever man takes a harvest of wildlife, he is interfering with natural regulation. If man takes a limited harvest—no more than the *maximum sustained yield*—he can depend on these animals and plants for years. Maximum sustained yield represents the greatest number of animals or plants that can be taken year after year. In many cases, the maximum sustained yield is obtained when a plant or animal population is reduced to about one half its original, unharvested, size.

Good examples of this harvesting rule are found in the tuna fisheries off the coast of California and in the salmon fisheries of Alaska. For some fish, however, such as herring and sardine, the rates of harvesting can be much greater because these animals reproduce at high rates. For other animals, such as whales, however, the harvesting rate should be lower because these animals have relatively low reproduction rates

More complex principles of harvesting are based on how fast plants and animals grow; how many die naturally; and how many young are produced by parents at various ages. Although the mathematics involved may be very complicated, the fundamental idea is simple: how can we best use, and conserve, our renewable resources?

First, each group of young animals or plants usually starts life as a large number of small eggs or seeds. The total weight of these eggs or seeds—their *biomass*—is very little.

Second, as the young animals or plants appear and then grow bigger, their numbers become fewer. Many die through disease, starvation, and accident, or they may be eaten by other creatures. Nevertheless, their total weight—the biomass—becomes greater for a time with the increasing age of the group.

Finally, there may be only one large survivor left. When it dies the biomass becomes zero. At some age before zero biomass, however, the biomass reaches its largest figure. If you were, say, a farmer, you would harvest the plants and animals at this age—precisely what foresters and fishery managers aim to do.

FISH, GAME, AND FOREST CONSERVATION

All harvesting plans must take account of the need for animals and plants to produce more members of the species. When

Weyerhaeuser Company

A research forester examining test groups of young tree seedlings that are being grown under laboratory conditions. Such studies help determine the insect and disease resistance of certain tree varieties – information important for all reforestation programs

harvesting rates are high, or natural reproduction is poor, it may be necessary to provide artificial assistance, such as tree nurseries and fish hatcheries. Although the reasoning behind these measures is obvious, finding the best ways of helping nature has proved difficult.

Fish hatcheries, for example, have on occasion been highly successful. But after years of experience, conservationists have learned that many of the lakes and streams that were "stocked" with fish had high rates of natural reproduction in their original populations anyway. Also, many fish hatcheries spread diseases. In only a few situations are hatcheries necessary and economically sound. Nevertheless, they are of some value, particularly for selected species.

It is often wiser and cheaper simply to improve natural environments for fish. The construction of reservoirs to ensure streamflows, the providing of spawning facilities, and other measures of this type have been widely successful.

Similar steps may be taken in managing waterfowl and wildlife generally. One good example is the protection or establishment of marshes where water birds can breed. If this conservation work had not been undertaken, there now would be far fewer nesting sites for ducks and geese. There would be no refuges for them during their long seasonal migrations. In much the same way, setting aside winter ranges for elk and mountain sheep guarantees their survival better than just feeding them.

The same theme is stressed in modern forest conservation. While reforestation by man of logged or burned areas is frequently desirable, unsuitable species of trees may be planted. Natural reforestation will occur if trees are cut down in small patches, and if large fires are prevented or fought. Limited fire itself is a promoter of natural forest growth. These and similar measures are better and less costly than large-scale re-planting with seedling trees from nurseries.

There are many possibilities in modern techniques of ensuring future harvests of fish, wildlife, and trees. The best harvests should be based on strengthening, rather than replacing, favorable natural processes.

CONSERVATION OF THE SOIL

Soil is often classified as a renewable

resource, but it develops very slowly by the gradual weathering of rock or sediment. The entire process may take less than a century or range up to many thousands of years.

Once soil is ruined or disappears, it is almost impossible to restore in large amounts. As yet there is no practical artificial soil. To some extent, of course, soil can be improved by means of certain crops, mulches, manures, and chemical fertilizers. It can be irrigated, or artificially watered. Also, relatively small amounts of topsoil can be brought in and spread for home gardening or limited commercial crop production. But these measures are no substitute for good natural soil. With proper management, a good soil will yield adequate crops for many generations of mankind.

No large or important crops can be grown without soil. So-called "soilless agriculture," or raising plants in watery mineral solutions, is not widely practiced at present. Conservationists have made great efforts to awaken the public to the tragic consequences of soil erosion and infertility and how they can be prevented.

Too-frequent tilling of the soil and plowing it without regard to the contours of the land may lead to massive soil loss. Cutting down most or all of the trees over a broad area, overgrazing of herds, and slipshod road building, among other poor practices, also cause erosion of the soil. Uncontrolled flooding washes away tremendous volumes of soil into the nearest river, lake, or sea. Even if the soil remains, it may become exhausted by improper farming. The end result is sometimes a desertlike expanse of dunes—a "dust bowl."

Extensive soil damage and loss are just about permanent. Consequently, many parts of the world are no longer able to produce the crops they once did. Many regions around the Mediterranean Sea, and in the Middle East, western India, and Pakistan, for example, were far more fertile hundreds to thousands of years ago.

A good deal of this area has been semiarid or dry for long periods. In ancient times the soil was therefore irrigated to produce very bountiful harvests at first. But minerals passed from the water into the ground. The resulting salt buildup through the centuries ruined the soil. In other cases, irrigation dams and canals were destroyed or neglected, and the land became desert again. It needs only water to yield crops once more.

This pattern has been repeated to varying degrees all over the world. The best soil

E.P.A. Documerica—Bill Gillette

Heaps of slag from a strip coal mining operation deface the land. Strip mining causes extensive environmental damage. To date, reclamation efforts have been minimal.

has often been scattered far and wide by the winds or rests at the bottom of the sea. Or the soil has been robbed of life-giving powers by crops and agricultural methods that restored nothing of what they took from the soil.

CONSERVATION OF WATER

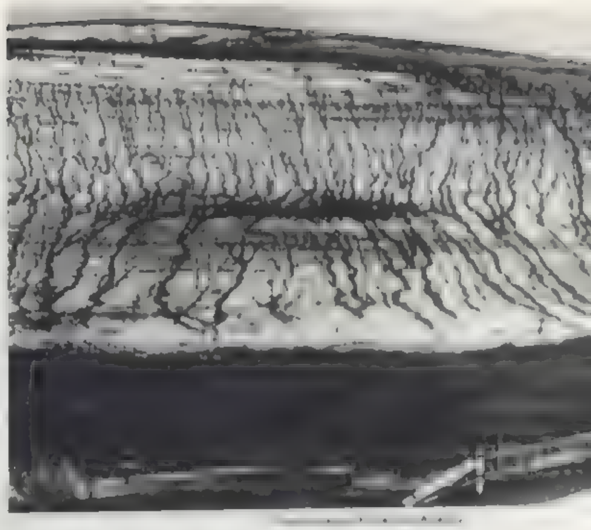
Soil loss is closely tied to loss of water. Where land is stripped of soil or at least of trees and other vegetation, surface runoff of rainwater is much greater than before. Should land slopes also be steep, water flows away quickly. If rainfall is abundant, floods are the result. In any case, much soil is carried off by the racing waters.

Where the climate is dry or when there is a drought, any slight rainfall quickly evaporates from the bare ground, instead of being absorbed by plants. If the soil is sandy or porous, the water quickly sinks into it, to be trapped or scattered indefinitely. As a result, streams become mere dribbles or vanish completely from time to time. With occasional heavy rains in deserts, however, huge flash floods may sweep away enormous quantities of soil.

With all this loss of soil, plants find it difficult to grow. The fewer plants, the less soil that can be held in place. Thus the conditions for deserts continue to exist, perhaps becoming worse in a vicious circle. Even if desert environments do not develop, the loss of water and soil cannot easily be made up, if at all.

The problem of obtaining and conserving water is becoming crucial in many places. The main reasons are soil erosion, loss of forest cover, increasing population, and expanding industry. The results are exhaustion and pollution of water supplies. Obviously, fresh water is a resource that must be carefully managed, for it is becoming scarce.

The central idea of most water-conservation projects is to regulate the rates at which fresh water flows away. Ten per cent of the world's fresh water is now controlled with dams and reservoirs. Some of these structures date from ancient times. In Sri Lanka, for example, man-made lakes called "tanks" serve to store monsoon rainfall. In arid parts of Iran there is a system of underground reservoirs built many centuries ago.



Severe sheet erosion has occurred on this field. Reclamation will be a long and difficult job

Since 1950 there has been a considerable increase in dams and reservoirs all over the world. In the United States alone, more than a thousand small reservoirs a year are built. As the need for water grows, increasing attention is also being paid to plans for large-scale diversion and storage of water for entire continents. The Snowy River Project in Australia is one example; it also supplies water for power. Similar developments are being considered for North America. Also, desalination of seawater offers some promise.

There are, however, serious side effects coming from large-scale dam, canal, and reservoir projects, which conservationists worry about. When large bodies of water are diverted to another area, there may be changes in the local climate, because of changes in the rate and amount of evaporation of the water. Water-conservation developments also affect the environment in other ways. Vegetation, wildlife, and the land itself and its drainage patterns are altered.

Some of the results have been almost disastrous, as in the state of Florida and in the Far West of the United States. There is only so much water to go around. Some regions have lost most of their supply because of "conservation" projects.

Fish particularly are affected by water developments of all kinds, for good and for bad. Generally speaking, where reservoirs are built and streamflows are regulated, fish benefit. They increase in numbers and become of commercial or recreational value.

Special problems are created, however, when rivers that serve as routes for migrating fish, such as salmon, are dammed. Where a dam is less than 30 meters high and river flow is small to moderate (560 cubic meters per second at most), it is possible to help salmon go upstream. This is done by providing fishways and so-called fish ladders—series of ever-higher pools—enabling salmon to leap over the dam in stages.

Where a dam is over 30 meters high or streamflow is very great, it is difficult to build fishways and fish ladders. Many salmon and other fish are prevented from migrating upstream. Young salmon later swimming downstream toward the sea are killed or injured as they pass through the dam or its water turbines.

The needs for water conservation may thus conflict with those for fish conservation. Careful analysis must be given each situation to ensure the best solution.

AGRICULTURE AND CONSERVATION

Linked to wildlife, soil, and water conservation are the effects of agricultural practices. In recent years new agricultural technologies have enormously expanded the production of crops and meat, but they pose rather serious problems.

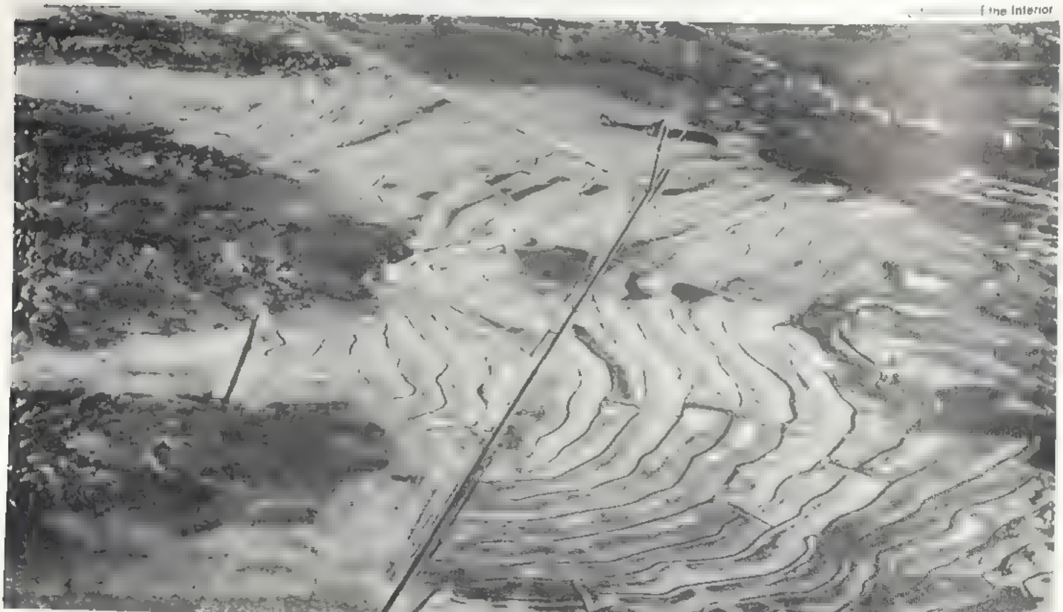
Among reasons for the unusual productivity of modern agriculture are new breeds of domesticated plants and animals, the wide use of machinery, large farms, and heavy application of chemical fertilizers and pesticides. Many of these practices have also been extended to animal culture. Their side effects, however, have not always been so fortunate.

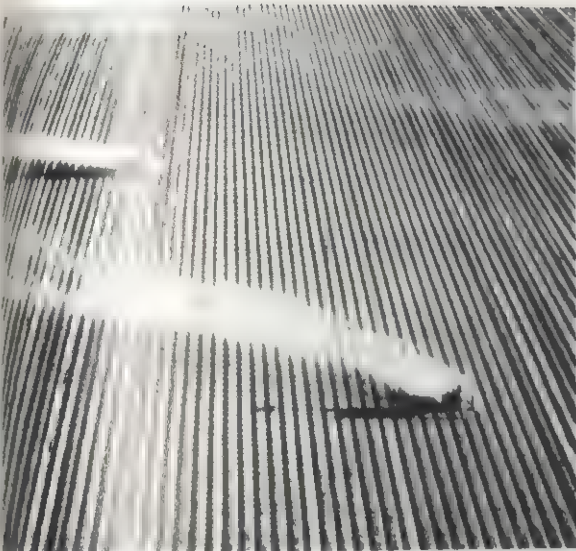
Pesticides. Many common pesticides, for example, kill beneficial creatures as well as dangerous ones. Insects that destroy pests also perish, as well as valuable birds, fish, and mammals. Chlorinated hydrocarbons—pesticides, such as DDT, containing chlorine, hydrogen, and carbon—have gained the worst reputation. They last for a long time or are changed into still more dangerous compounds in nature.

Such pesticides or their end products gradually build up in the bodies of animals,

This water-spreading system uses a series of dikes to capture spring or fall runoff. The water is used to irrigate land for crops such as alfalfa. Excess water is directed into a natural waterway.

of the Interior





E.P.A. Documerica, Charles O'Rear

E.P.A. Documerica, Gene Daniels

Large-scale farming of one particular crop is efficient but it disturbs the balance of nature and increases the possibility of a disastrous plant-disease epidemic.

as in many birds and fish. In some cases, the birthrates of these creatures have dropped to the danger point because their eggs were damaged by the DDT.

Moreover, numerous pests, especially insects, have become resistant to DDT and similar pesticides. As new pesticides replace older ones, new strains of pests become resistant to those as well.

The solution to this problem is to stop the use of chemical pesticides, unless all other control measures fail. One alternative to the application of pesticides is biological control. For example, animals and diseases that prey on pests may be deliberately introduced, or scientists may greatly reduce pest populations by releasing large numbers of sterile male pests into the wild during the breeding season. The use of chemical pesticides can also be reduced by the breeding of races of domestic plants and animals that are themselves resistant to various pests and diseases.

Fertilizers. If pesticides are dangerous, so are chemical fertilizers. The advantages of nitrate and phosphate fertilizers are offset by their long-term effects, particularly on water supplies. Wherever fertilizers are overapplied, they are washed out of the soil into groundwater, streams, lakes, marshes, and seas. Nitrates can be directly poisonous to human beings. Increases in the nitrate content of drinking water have alarmed health authorities and have led to widespread monitoring of nitrate levels.

Phosphates may be as harmful as nitrates. They promote the growth of plants in water as well as in soil. If enough phosphates get into lakes and streams, they stimulate the reproduction of blue-green algae. When polluted with phosphates, a once-clear lake soon becomes fouled with a thick bloom of algae.

If phosphate pollution continues or increases, more growths of algae and other aquatic plants choke the lake. In a relatively short time it takes on characteristics that it would not have naturally until hundreds or thousands of years later. The aging of a lake, which ultimately leads to its complete filling-up with plants and soil, is termed *eutrophication*. Eutrophication is speeded up by phosphate pollution, as well as by sewage (which often contains phosphate from detergents) and soil erosion.

Monoculture. In addition to pesticide and fertilizer pollution, intensive modern agriculture has other untoward effects on

nature. The total amount of land under cultivation has decreased markedly during the last few decades in technologically advanced countries, such as Canada and the United States. Yet is has become more profitable to operate very large farms. One such farm may cover many thousands of hectares. This leads to simplification of living things in a locality. Great numbers of relatively few types of domesticated animals and plants compete with and overcome much of the native fauna and flora.

So-called *monoculture*—concentration on one type of agriculture—leads to unstable relationships among animals, plants, and soil. The balance of nature is disturbed. Because land is being used intensively, outbreaks of pests and disease are more frequent, and soil conditions may become poor. The soil and the water may be poisoned by seepage from the manure of animals that are kept in large yards. Only through sustained human effort can high agricultural yields be maintained.

In an attempt to offset these effects, conservationists manage soil, land, and water resources so that they will be of maximum benefit in many ways. As new areas are opened to agriculture and other kinds of human settlement, many mistakes of the past are thus not repeated.

The same statements are true, in some measure, of the new and developing nations. Conservation principles are being applied there to agriculture and forestry. Unfortunately, the differences in climate make certain of the more traditional principles of little value. The lessons learned in temperate climates often do not work in tropical lands.

Climatic problems. Tropical soils easily lose much of their mineral content because of periodic heavy rains. When such lands are cleared of jungle or other growth, the fertility of the soil speedily drops. Poor harvests are the result. The soil then becomes very hard and will not even support the original wild vegetation any longer.

Experience is also lacking in the management of arctic and subarctic lands. These northern soils are often permanently frozen at some depth, forming *permafrost*. Once the soil surface is broken, the ice melts and a water-soaked bog results. Almost no crops can be grown in acid bog soils, and it is very difficult to build anything on such semiliquid foundations. Much research is needed to improve conservation techniques in arctic, subarctic, and tropical regions.

CONSERVATION OF MARINE RESOURCES

The sea and its resources have recently become a major worldwide problem. This is especially the case with fish and other forms of life that make the sea their home. In 1950 the world catch of fish came to 32 million metric tons; in 1980 it was more than double that—70 million metric tons. According to the best authorities, the ocean's maximum sustained yield of fish cannot go much over 100 million metric tons per year. We are rapidly approaching that limit. In fact, in some areas of the world the catch has already exceeded the maximum sustained yield.

The prime reasons for the enormous increase in the fish catch are the steep rise in population since 1950 and the [illegible] advanced fishing methods now being used. Modern acoustic devices easily locate once-elusive schools of fish. Millions of fish are swept up in huge mechanized nets and stowed in the holds of great ships for weeks on end. They may even be processed on board, to be ready for consumers when the ships come into port.

Most of this catch is in highly productive waters near shore. This situation has caused local fish shortages and, therefore, hot international arguments. In some cases, nations send naval units to protect their fishing craft and grounds against intruders. Many of these difficulties, however, have been resolved by fishing treaties that have partly succeeded in developing conservation measures. For many of the world's fisheries, though, there are no international agreements other than the provisions of the "Law of the Sea" and several international commissions establishing guidelines for specific fisheries.

Until 1977, the Law of the Sea provided that each nation with a coastline had

control of fisheries up to 19 kilometers offshore. Beyond that limit the sea was wide open to all. The result was intense rivalry and overfishing. Some national governments arbitrarily extended their jurisdiction far more than 19 kilometers offshore in order to claim certain fishing grounds for their exclusive use. Then, in 1977, most nations of the world declared Exclusive Economic Zones, laying claim to fisheries up to 320 kilometers from shore. This has been an important conservation step and will mean wiser use of resources in the future.

Sea animals other than fish are also sometimes dangerously overharvested. Marine mammals are a valuable resource, and various international commissions have been set up to study and recommend management guidelines for harvesting these animals. In 1972 the U.S. Congress passed The Marine Mammal Protection Act, which banned whaling from any U.S. ship and placed strict limitations on the taking of dolphins and other marine mammals.

Marine mineral resources as well as marine life are being increasingly exploited. Offshore drilling for oil has grown tremendously since the 1960's, with its attendant evil--pollution of the sea. The need for water, fuels, and other minerals is driving some nations to explore the ocean and its floor intensively. If any serious scramble for the ocean's supposedly unlimited wealth ever begins, those nations with long coastlines, much money, and technical know-how would have the advantage. Only international agreements will conserve the resources of the sea and ensure the less-favored nations a fair share of them.

NONRENEWABLE RESOURCES

Nonrenewable resources are those whose natural formation is so slow—taking thousands to millions of years—that, for all human purposes, they may be regarded as being fixed in quantity. Most rocks and minerals are nonrenewable: coal, oil, natural gas, metallic ores, phosphates, and many others. Once they are used up, there is no way to replenish world supplies, unless we recycle waste materials into production or rely on synthetics.

Scientists are trying to develop ways of controlling insect pests biologically and thus avoid the use of pesticides. Above is a trap coated with a sex hormone that scientists hope will effectively attract the western pine beetle, a serious pest

CONSERVATION OF PHOSPHATES

Phosphates are highly important minerals, essential to life in plants and animals. They are often used as chemical soil fertilizers and in detergents. Man's activities have now reached a point where they are measurably influencing the distribution of the existing amount of phosphates.

To begin with, phosphates are extracted from phosphate-bearing rocks. When they are applied in agriculture, they are fixed in, or become part of, the soil and the crops. But a significant quantity of

Richard Nowitz/Black Star

In Israel, large areas of desert have been reclaimed and are now under cultivation. Irrigation with desalinated water is often necessary. Here, a farmer raising tomatoes in sand adjusts a drip irrigation system for the most efficient use of water.

excess phosphates is washed into lakes, streams, and seas, where it accumulates in the sediments, or mud and sand, on the bottom.

That fraction of the phosphates absorbed by crops becomes broadly distributed. After the crops are harvested and used, much of their phosphates are eventually discharged in sewage and end up in sediments also. Phosphates in detergents share the same fate. Thus, a great deal of the mined phosphates finally become part of the seabed without much chance, at present, of being economically recoverable.

Present world reserves of phosphorus in phosphate-bearing rocks are estimated at 3 to 6 billion metric tons. At current rates of phosphate-fertilizer use, these supplies should last for 400 years. But there is no assurance that fertilizer use rates will not rise sharply as a growing world population demands more food and thus a more intensive agriculture. If this should happen, the reserve of mineral phosphates may run out in less than a century.

We should, therefore, consider ways of conserving phosphates. These measures would include more careful mining of phosphates and using less fertilizer.

CONSERVATION OF MINERALS

Power, or, rather, the minerals that furnish power—coal, oil, and natural gas—are already in short supply in some places and will not hold out indefinitely. These energy-yielding substances are also called *fossil fuels,* because they were formed through millions of years from the remains of animals and plants. It is hoped that nuclear energy will replace fossil-fuel energy in the future. But many people object to nuclear power plants. The disposal of radioactive wastes is a major problem because they remain radioactive, and therefore hazardous, for hundreds, thousands, and even millions of years.

The world reserves of fossil fuels are not fully known. As demand for them has increased, exploration and exploitation have progressed also, even into the oceans. The continental shelves—those portions of the continents extending outward for some distances underneath the sea—have proved to be abundant sources of oil in some areas. Also, land areas once remote or inaccessible are now being tapped for oil and gas. The Arctic slopes of Alaska and the frigid wastes of Siberia are well-known examples.

It is not only a question of the existing amounts of gas, oil, and coal. Is technology adequate to the job of exploration and exploitation? How about transportation of the fuels to market? Is the market profitable enough to justify the higher prices that may have to be charged for these fuels? For example, shale oil—oil very tightly bound to a certain type of rock—is a good fuel, but very difficult and costly to extract.

Conservationists must also ask: "What

effects will drilling, mining, and transportation have on the environment of the exploited region?" All concerned must answer the questions asked above. They must weigh the advantages to man against the possible harm to nature and to other resources if fossil-fuel deposits are to be exploited more intensively. For example, strip mining of coal is far cheaper than underground mining. It thus makes more coal available at lower prices. The effects of strip mining on land and water, however, are often devastating. As another example, spills of oil from tankers or offshore wells pollute the sea and its shores, killing many forms of marine life.

Other mineral resources besides fuels may also be inadequate to our increasing demands. Will we have enough metals—iron, copper, aluminum, and so on—for our needs? Even if many metals are replaced by synthetic materials, such as plastics, these materials are frequently made from chemicals present in coal, oil, or gas. We are then right back where we started.

POLLUTION OF THE ENVIRONMENT

We have already described some polluting effects of modern industrial and agricultural practices. Not only are land, fresh waters, and the ocean affected, but the atmosphere as well. There is the problem of polluted air endangering our health. There is also the broader problem of conserving the atmosphere as a resource, for the atmosphere supplies life-giving oxygen and water. It also affects world temperatures.

Because our homes, factories, autos, and planes belch smoke and gases continuously into the air, we may be upsetting the atmospheric balance. Authorities have already measured a slight increase in the carbon-dioxide content of the entire atmosphere since the early 1900s. It is probably a result of all the fuels we burn hour after hour.

Since carbon dioxide has an insulating effect, some scientists fear a worldwide rise in the temperatures of the atmosphere. If such a rise should continue, the climate might become warm enough to melt all or most of the polar ice. The sea level would then rise, and many low-lying lands and cities would be flooded.

On the other hand, all the smoke and dust we release daily into the air may bring on the opposite result—worldwide cooling of the atmosphere as the sun's rays are blocked. As temperatures fall, a new ice age may follow.

These ideas, of course, are mere speculation at present. But must we take such chances? Are not the effects of environmental pollution dangerous enough now to warrant our taking drastic steps to curb it?

Consider all the unnatural substances we pour into the environment, regardless of whether they are actually poisonous or not. Should we be surprised if some kind of natural balance is disturbed? Anything in large enough quantities may be bad. Once they enter nature, man-made substances may be broken down into harmless matter—or they may be chemically transformed into deadly poisons.

Consider DDT. The man who discovered its pesticidal quality was awarded a Nobel Prize. DDT has destroyed many dangerous insects. For example, it totally wiped out malaria in numerous countries that had been afflicted with this dread, mosquito-borne plague for centuries.

Yet, because of its dire effects on many living things, as we have noted, conservationists now regard DDT accumulation as a very serious problem. The pesticide is legally banned in the United States. But some authorities predict that, despite these measures, DDT will mount in the environment for several decades to come. The reason is its very heavy use in the past and its slow cycling into the environment.

Not only are many chemicals pollutants, but excessive heat and radiation are too. Factories and power plants, especially nuclear plants, discharge enormous amounts of heat into streams and lakes whose waters serve to cool their machinery. Such *thermal pollution* raises the average water temperatures enough to kill or drive away many fish in the affected streams and lakes. Heat discharged directly into the atmosphere has similar thermal effects on the local weather.


World Wide Photos

The Transamazon Highway, cutting through the heart of the dense Amazon jungle, is of serious concern to conservationists, who point out that destruction or serious alteration of the ecology of the tropical rain forest will have many effects.

A PHILOSOPHY OF CONSERVATION

From what has been written here, it is clear that conservation must have new aims if it is to remain a useful philosophy. From an individual or family practice among hunters, herders, and farmers, conservation developed into a major concern of organized groups. Then it became a powerful, legal national force in different countries. Now it must assume truly worldwide scope.

The reason for the internationalization of conservation is the vast web of commerce and industry that spans the world today. No longer are most localities and countries self-sufficient in their resources, industry, and agriculture. Bananas are exported from the tropics, tin from Bolivia, and many manufactured items from Japan. Goods—the good things of life—are obtained on a worldwide basis. But the "bads," or bad things, such as pollution and exhaustion of resources, are becoming too available as well.

If we think of our earth as a spaceship with limited resources, as one author has put it, we will surely become conservation-minded. You cannot stock a spaceship, no matter how large, with a never-ending supply of air, water, food, and materials. If a large part of this supply cannot be replenished or renew itself, we must conserve as much of it as possible. We must try to replace what we can replace. And we must limit the growth of population so as not to overcrowd the spaceship earth.

Human population itself is a natural resource. But it is a resource that is as hazardous in oversupply as in undersupply. To get the maximum benefit, population must be kept to a size that suits the available natural resources but is able to use these resources effectively and prudently, with a thought to the future.

Human beings must be conserved in that they should be kept healthy, able to fulfill themselves, and able to fill their roles in society. War, disease, famine, accidents, and natural catastrophes such as earthquakes, volcanic eruptions, and floods are destroyers of the human-population resource.

There are many choices open to us. We may adopt the attitude that the world of tomorrow will somehow find the technical means to look after itself. Or perhaps we don't care at all. At the opposite extreme, we may become fearful and strive to return to a more primitive way of life, giving up many of mankind's hard-won technological achievements.

Between these two extremes there are many views, including those of the conservationist. The final solution may not have to be either a polluted, overindustrialized world or a pastoral-agricultural society. It could be a world where there is wise, moderate use of natural resources by a well-developed technology.

The conservationist is primarily concerned with tempering the rate of industrial change so that various choices for the future are not forever lost to us. The essence of conservation is really foresight and order in the conduct of human affairs, with particular attention to the ways in which the resources of our planet are used.

HOW WATER CHANGES THE LAND

by Norman E. A. Hinds

Running water is one of the most important agents eroding the surface of the earth. During and after rainstorms and the melting of snow and ice, water may run downhill in a sheet over the land, forming what is known as a *sheet flood*. Great quantities of water also circulate either temporarily or permanently in the more concentrated flow of streams and rivers. Sheet floods wash immense quantities of rock fragments down slopes. Streams transport even larger quantities as they carve out their valleys. As a result of all this activity, a great variety of landscapes are created.

Clouds release their load of moisture in the form of rain, snow, hail, sleet, and mist. Part of the water that falls on the earth's surface goes into streams, rivers, lakes, and oceans; this is called *runoff*. Part is evaporated back into the atmosphere or is transpired by plants. Part, as well, is added to the underground supply of water by sinking into the myriads of open spaces in rocks and in rock mantle—the rock debris that covers bedrock. Part of the precipitation is locked up in fields of ice and glaciers—in some cases, for many thousands of years.

As far as we know, rain or snow falls on all parts of the earth's surface, but the amount and frequency vary widely. At Arica, in the Atacama Desert of Chile, the annual rainfall averages 0.8 millimeter. Over parts of this desert, no rain may fall for as much as 5 to 10 years. In wet tropical and subtropical regions, rainfall may reach more than 2.5 meters a year, as at Cherrapunji, India. There, however, the usual precipitation is a little more than one meter yearly. In most populated areas, annual precipitation averages from about 50 to 150 centimeters.

Union Pacific Railroad

THE RISE OF SHEET FLOODS

Much damage to the surface of the earth may be wrought by catastrophic flooding: that is, by unusually heavy falls of rain causing extensive sheet floods. If little or no water is evaporated or absorbed by the ground, immense quantities of water pour down along the surfaces of slopes. Such sheet floods may also lead to stream flooding if they fill watercourses beyond normal capacity. Sudden disastrous flows of water are generally called *flash floods*. Sheet floods may also occur when sudden rises in temperature in winter and spring quickly melt snow and ice. Such floods are particularly devastating when quick melting is accompanied by heavy rains.

The erosive effects of sheet floods are determined in large part by the amount of water flowing down a slope, by the steepness of the slope, and by the velocity of the flood. The resistance of the materials over which the flood travels also affects its erosive action. This action is particularly great if the sheet of water attacks weak rocks or rock mantle. Sheet floods are not nearly so erosive if the plant cover is reasonably dense. The impact of falling rain is received chiefly by the plants, through which and down which the water drips or trickles to the ground. The living plants and the litter of dead plants on the gound divide the sheet flood as it moves down slopes, thus lessening its force. Roots, especially the intricate root systems of the smaller plants, bind the soil particles together and make them resistant to the onrush of the flood

SHEET FLOODS SCULPTURE THE LAND

In all regions, sheet floods are sculptors, shaping the land by washing loose rock fragments down slopes and eventually into streams that carry them away. In arid lands, especially in deserts, the erosive effect of falling rain and sheet floods is most conspicuous because vegetation is scanty or entirely absent and because rainstorms are frequently violent. The floods also cause great damage in humid regions where the plant cover has been partially or completely removed by natural causes or by man. Wind erosion often works together with sheet floods in producing changes.

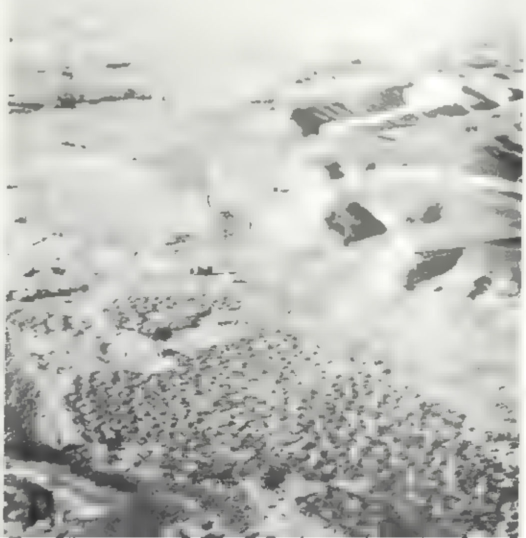
Where plant cover is inadequate or absent, sheet floods form *gullies*, which are generally narrow V-shaped trenches. As gullies are eroded, sediment is swept into streams, dry valley bottoms, or low areas beside slopes. Starting as shallow furrows, the gullies may become tens, scores, or even hundreds of meters deep

Glaciers, such as Peyto Glacier (far left) in Banff National Park, Alberta, Canada, and their meltwater streams form deltas and change the land formations in their area.

Jerome Wycoff

Sheet flooding that occurred some 18,000 to 20,000 years ago, plus other geologic processes have carved out the starkly scenic area known as the Scablands in eastern Washington

U.S. Geological Survey, U.S. Dept. of the Interior



The chief type of landscape developed primarily by sheet floods is *badlands*. It is a labyrinth of deep, mostly narrow gullies, separated by ridges with rounded or narrow crests. Badlands are most likely to evolve in arid or semiarid regions, such as the western Dakotas and central Wyoming in the United States. Those that develop in more humid areas often represent a serious problem, since valuable or potentially valuable farm or pasture land becomes entirely unproductive.

If sheet-flood erosion takes place along closely spaced fractures in weak rock or rock mantle, isolated pillars of various sizes are formed. Pillars are also developed in areas where weak rock or rock mantle is covered at intervals by boulders or flat slabs. These protect the weak materials beneath them from erosion, while the intervening areas are etched out. At first the pillars retain their capstones, but eventually these fall, leaving more or less sharp-pointed pinnacles. Continued erosion causes these pillars to collapse.

In most rock masses, some sections are less resistant to erosion than others. On exposed faces, the weaker or more weathered parts are eroded by rainwash. This erosion gives rise to etched or honeycombed cliffs or slopes and to cavernous openings in rock walls. Occasionally natural arches are formed.

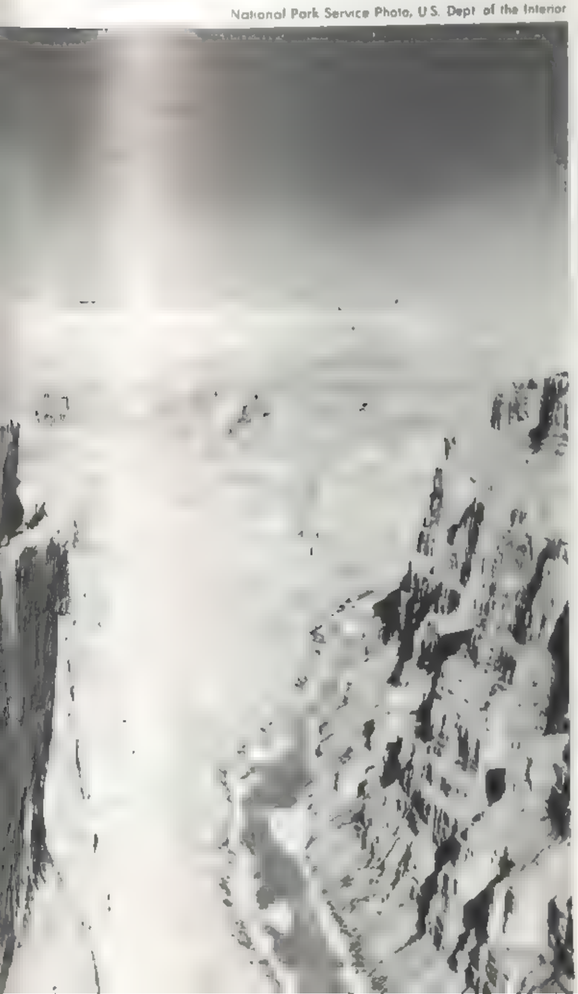
If masses of resistant rock are surrounded by weaker rock formations, the latter may be so washed away that the resistant materials will stand out as eminences above the general surface. Ship Rock Peak, in northern New Mexico, is a formation of this kind; it is the neck of an ancient volcano and is surrounded chiefly by soft clays. Another good example is the Devil's Tower, in northern Wyoming.

Falling rain and sheet floods play an important part in modifying the surface of arid regions where there are horizontal or nearly horizontal strata. If these strata vary in their resistance to erosion, torrential downpours slowly excavate or weaken the materials below the more resistant layers. Eventually the mass above is insufficiently supported and joint blocks break off. Frost wedging and other agents also aid in this process. If such erosion is long continued and the weak zones are fairly thick, cliffs may retreat many kilometers, and gently sloping terraces are developed.

As cliffs retreat, blocks of resistant strata are isolated from the main mass and form mesas, buttes, monuments, and pillars, showing a great variety of forms. Magnificent examples of all these features can be seen in the Grand Canyon of the Colorado River in Arizona and in other parts of the Colorado Plateau, through which this river flows.

The magnificent Grand Canyon was carved out in the course of centuries by the Colorado River and its tributaries. Certain rock strata resist the force of the water more than others, causing different rock formations

National Park Service Photo, U.S. Dept of the Interior



FLOW OF STREAMS AND RIVERS

An immense quantity of runoff water is

collected, as we have seen, in streams and rivers. A stream is any natural watercourse, large or small. A river is a large stream. These drainage lines are developed in natural depressions, some of which are due in part to sheet floods. If a depression has a free, or open, side, water will flow through it and a stream will develop. Otherwise a lake or swamp will be formed. Streams and lakes may also be fed by underground water seeping into their beds.

The depression, or valley, through which the stream starts to flow is gradually modified in form. It may be widened and deepened as a result of erosion until it becomes a huge excavation like the Grand Canyon of the Colorado. On the other hand, the main activity of many streams is the deposition of sediment, which gradually fills the original depressions. This condition is found along great stretches of the Mississippi and Nile rivers.

Streams vary greatly in length and width. The principal rivers of the earth are trunk streams which receive the direct or indirect flow of countless tributaries; the whole is called a *river system*. The area that is drained by the river is known as the *drainage basin*. In the case of large rivers, this basin may cover a considerable part of a continent.

In the humid parts of the tropical and temperate zones, large streams and most of their tributaries are permanent. In more arid regions, some main streams and most tributaries are intermittent—that is, their flow ceases for a certain period of time. Few streams are permanent in desert regions. They flow principally during and after heavy rains or the melting of snow and ice in nearby mountains. Where winters are long, the smaller streams are deeply frozen during the colder months so that little or no water flows through their channels. Large streams have a cover of ice more than one meter thick, which reduces their volume.

The *channel*, or *bed*, of a stream is a trench having a roughly U-shaped cross section. It is the space normally covered with water. In rivers that spread over adjacent flats or bottoms, the channel normally containing the water is called the *minor bed*. The area covered by flood waters is the *major bed*.

The velocity of a stream varies along its length and also in different parts of a given cross section. The controlling factors are the gradient, or rate of slope, of the bed; the volume of water, the friction between water and bed; the shape of the bed; and the load of rock fragments that the stream carries.

The flow of a stream is called its *discharge*. In most cases, discharge increases downstream because tributaries, seeps, and springs all contribute water to the stream. In arid regions, however, there is generally a lessening of discharge downstream because water is lost as it sinks into the ground or evaporates. Practically all streams pass through a volume cycle between an extreme low to a flood peak. There are also minor cycles between these limits.

Flood waters never overtop the walls of deep, narrow canyons—hence the record of their passing is revealed only by erosion and deposition along the canyon walls. In the case of lowland streams, the waters of the ordinary flow are contained within the normal or minor bed. When this is completely filled, the stream has reached the bankfull stage. It is at the overbank stage when its waters flow over its banks and flood the adjacent lowlands.

In small streams, there is generally quick flooding; the flood crest rushes swiftly downstream. In large rivers the water rise is more gradual, and the flood crest proceeds more leisurely. It takes weeks for floods starting in the upper Ohio or Mississippi to reach the mouths of these rivers.

TRANSPORT OF MATERIAL

Streams transport varying quantities of weathered rock fragments and a great deal of animal and plant debris. They also carry, dissolved in their waters, many mineral and organic substances. The total of this material is called the *load* of the stream.

The undissolved load of a stream may range from minute particles of suspended clay to large boulders, which are rolled, bumped, or pushed along the bed. The distances that rock fragments travel in water

New York State Department of Commerce

Elephant's Head is one of the striking rock formations found in Ausable Chasm, a deep gorge in the Adirondack Mountains of New York. It was formed as the Ausable River cut through sandstone

before being dropped depend on their weights, sizes, and shapes, as well as on the volume and flow of the stream itself. The heavier, larger, and rounder bodies usually require fast-moving or even turbulent waters in order to be transported. They are often picked up last (if at all) and then released first when speed or volume of flow diminishes somewhat. The finer materials are frequently carried the farthest and are deposited only when the current slackens still more or ceases entirely. However, if the drop in water volume and speed is sudden and extreme, practically the entire load (coarse and fine) may be deposited at once. Dissolved materials may be precipitated out when the stream loses much water through evaporation or when it enters the sea, where the current slackens.

Conditions may be such that fine sediments are caught up at the same time as the coarser matter, or after it, or perhaps not at all. Dense clays, adhering firmly to the bed, may resist being moved along by the stream. The stream, if turbulent enough, may transport sand and pebbles instead and perhaps drop them a considerable distance away. However, once the fine sediments are in suspension, they are usually moved farthest even by gentle currents. The net results of all the activities described above are stream deposits of highly varied character, ranging from beds of fine clay to piles of large stones and often including mixtures of clay and stones.

Some streams carry chiefly sand and coarse fragments except during times of flood, when much fine debris is washed in by tributaries and sheet floods. Such streams are clear when the water is low. Other streams are muddy most of the time since the greater part of their load consists of fine material kept in suspension. Large boulders are moved only by major floods and are found principally along mountain and high-plateau streams, which have steep gradients and consequently high velocities. Small boulders, pebbles, and gravel are most abundant along such streams. However, they may be swept onto lowlands by great floods. Sand, especially the finer grades, and mud are found particularly in low-gradient stretches.

The material in solution comes principally from spring waters which have dissolved mineral and organic materials underground. The amount of dissolved substances transported by streams is very great. Each year the Mississippi carries an average of 125,000,000 metric tons of material in solution and, at the same time, an average of 345,000,000 metric tons of rock fragments.

CARVING VALLEYS

As fragments are carried downstream they abrade the beds of streams: that is they wear them away by friction, thus widening and deepening them. This is one of the principal factors in the erosive action of streams. Flowing water, using its load of sediment as a gouging tool, can carve out canyons hundreds of meters deep even in the most resistant rock. Another important factor is hydraulic action: the impact of flowing water on weak rock or rock mantle loosens and quarries out fragments or even

masses. Flowing water also dissolves small amounts of soluble materials in rock, especially in such formations as limestone or gypsum.

By removing weathered material and abrading the bottom and sides of its bed, a stream gradually excavates its valley. In doing so, it works in two directions—downward and from side to side. For a time after a stream begins its flow over the land, downward erosion is rapid if both the elevation of the land and the slope are great enough. The resulting stream velocity is high; therefore the abrasive action of particles coming in contact with the bedrock is very powerful. As the slope of the bed decreases, downcutting falls off.

Sideward erosion goes on because all streams have irregular courses and the water, with its load of sediment, is thrown first against one bank and then against the other. This type of erosion is due to the removal of weak materials by the force of water and to the more gradual undercutting of resistant rock by abrasion.

In the course of time, cavernous openings are excavated in the valley sides. Eventually great masses of unsupported rock above the cut fall, and as a result the valley is widened. Sideward erosion is most active along concave banks against which the water strikes with greatest force. The channel gradually becomes more crooked and the windings called *meanders* are developed. The word "meander" is derived from *Maeander*, an Asian river famous for its windings. Later, channels are cut through the necks of meanders, forming islands. The main current then follows the shorter route. Gradually the entrances to the bypassed channels are filled with sediment, leaving crescent-shaped lakes, called *oxbows*. The oxbows formed in this way may likewise be filled in the course of time.

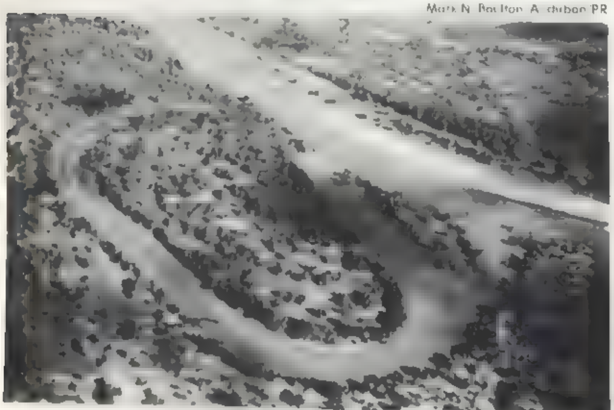
Valleys are lengthened both downstream and upstream. Upstream lengthening comes about because the waters of the stream erode backward into the valley head. The downstream extension of the valley comes to an end when the stream joins another stream, flows into a lake or ocean, or disappears by evaporating or sinking into the soil. Upstream lengthening continues until the power of the backwaters is insufficient to erode back the valley head.

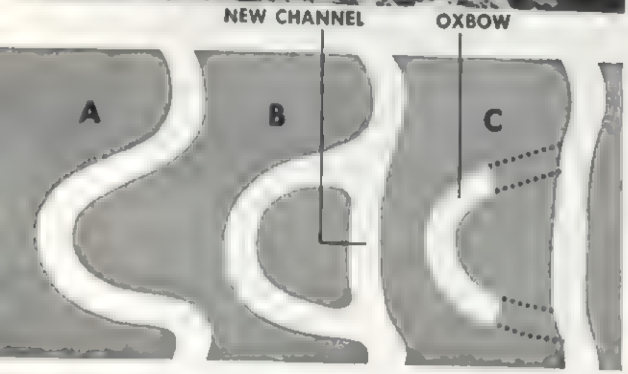
Tributary valleys are formed at the same time as a main valley because water flows down the depressions that are always present in valley walls. Most tributaries enter a main stream at the level of the latter; this is called accordance of level. In some places, however, the mouth of a tributary hangs above the main stream and the water plunges over a precipice to join the master channel.

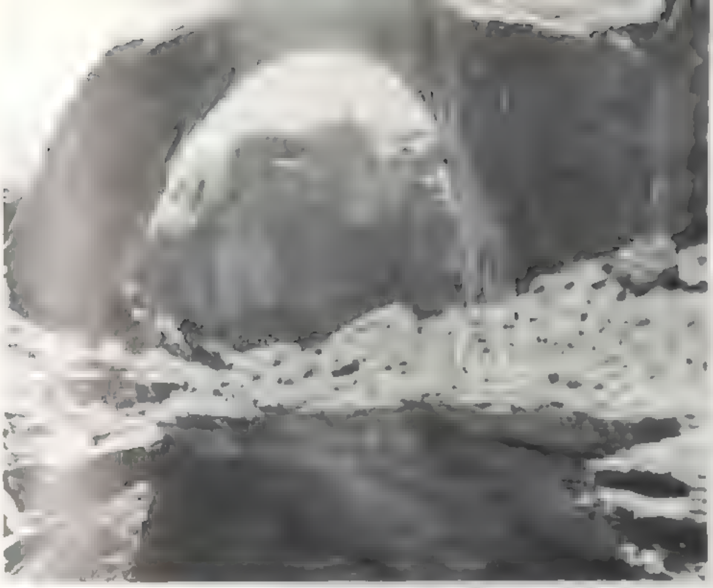
Streams erode their channel downward until they reach the basin into which they empty. The level of this basin is called the *erosion base*. Once this level is reached, the erosive action of the stream comes to an end. Most drainage systems flow into the

An oxbow formation off Luangwa River in Zambia. The three stages in the formation of an oxbow are shown in the art below the photo. A. A meander develops. B. A new channel is carved out. C. The old channel is partly filled up and an oxbow develops. The oxbow itself may fill in time.

Mark N. Boulton, Audubon/PR







Continual erosion by a meandering stream or river eventually cuts through intervening rock barriers allowing the water to pass through an opening. The opening subject to further erosion and weathering enlarges forming a natural bridge such as the famous Rainbow Bridge (left) in southern Utah.

sea. The erosion base in such cases is theoretically sea level. Actually, however, large rivers scour their channels a little below sea level.

If a stream empties into a lake or inland sea or disappears in an arid basin, the surface of the lake, sea, or basin is the erosion base. Such bases are generally above sea level; in some instances, however, they are considerably below it. For example, the Jordan River flows into the Dead Sea at a point 390 meters below sea level.

FALLS AND RAPIDS

Falls and rapids are developed under a variety of conditions. When a stream passes from more resistant to less resistant rock, erosion is more rapid in the less resistant formation. Consequently, a cliff or steep slope marks the boundary between the two sections. The Great Falls of the Yellowstone River in Wyoming was formed in this way. In other cases, undermining or sapping along weak layers causes unsupported rock to break off along fractures and to develop steep slopes or cliffs. This structure is found at Niagara Falls, between Canada and New York State. As we have already pointed out, certain tributaries join their main streams by plunging over steep precipices.

Waterfalls are common in areas where there has been uplifting of fault blocks. They have also developed in regions once covered by glaciers. As a result of glacial action, the main valleys have been deepened more than their tributaries. After the ice disappears, the water plunges down the steep slopes marking the boundaries between tributary valleys and main valleys. Great numbers of waterfalls have originated in this way, as in Switzerland and western North America, where mountain canyons were occupied by immense glaciers in comparatively recent geological time.

NATURAL BRIDGES

Most large natural bridges result from the cutting through of narrow promontories that form the inner curves of many meanders in deep gorges or valleys. If the stream erodes caverns on both sides of the rock barrier, the intervening wall may eventually be worn through, allowing part of the stream to pass through the aperture, or opening. As the erosion continues, the opening is enlarged until all of the stream flows through it. The former channel is filled up in the course of time. The opening continues to be carved out while the thickness of the natural bridge decreases as its sides are weathered. The famous Rainbow Bridge, in the southern part of Utah, was formed in this way. So was the Pont d'Arc ("Arched Bridge"), in southern France.

Natural bridges develop in various other ways. Sometimes the narrow divide between two closely spaced tributaries is undercut. In some places a section of the

This view of the Nile delta, taken during a Gemini orbit of the earth, shows a fan-shaped deposit, a typical formation at the mouth of a river as it flows into a larger body of water—in this case, the Mediterranean Sea (left in photo). Israel is at top of photo, Egypt at bottom right.

NASA

roof of a cave may collapse, leaving part of the roof as a bridge. Wave erosion along shorelines accounts for many natural bridges, too. In the case of waterfalls, part of the water may work through a joint in the bed and come out below the brink of the fall. If the passageway accommodates all the water, the brink becomes a natural bridge.

STREAMS DEPOSIT THEIR LOADS

As the volume or velocity of a stream decreases, its transporting power is diminished and it is forced to deposit part or all of its load. Deposition occurs at various places along the course of a stream and always at its mouth.

Bars of sand and gravel are formed along the channels of a good many streams. They may be found along convex banks where the velocity of the stream is least. They also develop at the place where a fast-flowing tributary joins a main stream if the tributary is bringing in more sediment than the main stream can carry away. In some cases, bars develop at low water and are swept away in time of flood. Sometimes they are a permanent feature of a stream, though changing both their form and their position from one season to th

As a stream widens its a plain or terrace is formed. During floods, the stream spreads over part or all of this area. As the flood waters recede, a layer of sediment is deposited upon it. The area containing the sedimentary fill, which becomes more extensive with every flood, is called the *flood plain*, or deposition terrace.

Left: the delta of the Nile River in Egypt. Note the complicated system of channels into which the Nile has divided. Below: a cross section of a typical delta

When a swift stream flows from a mountain canyon onto an adjacent lowland, its velocity quickly decreases and it gives up most of its load, forming a deposit known as an *alluvial fan*. The slope of young fans ranges up to fifteen degrees; that of the older ones is much gentler. Alluvial fans are particularly well developed along the fronts of high, steep mountains in arid regions, where streams not only decrease in velocity as they leave the canyons, but shrink greatly in volume through evaporation and because of the sinking of water into the ground. As the deposit grows, it is projected farther and farther over the lowland and headward into the canyon. The union of many fans along a mountain front forms what is known as an *alluvial apron*.

As a stream enters a lake or ocean, the abrupt decrease in velocity causes it to deposit the debris that it carries. The deposition of sediment goes on more or less continuously. It is particularly great during floods. If the action of waves or currents is not too powerful at the mouth of the stream, a deposit called a *delta* is built up. The delta is a fan-shaped, layered formation sloping from the river mouth outward under the surface of the ocean or lake. The name comes from the Greek capital letter "delta," written Δ.

Certain parts of the delta may be built up above water level. In time embankments called natural *levees* are formed and they are projected seaward. The river spreads over this new land during every flood, and upon retreating adds sediment to it. Thus this deposition gradually increases the area of the newly emerged formation, which becomes known as a *delta plain*. In many rivers the delta plain is continuous with the flood plain.

During floods, water breaks through weak points in the natural levees and a branching system of distributary channels is formed. Between the levees of these channels there are depressions, which are covered by arms of the ocean or by lakes (if the depressions are isolated). The depressions are gradually filled as more and more sediment is deposited upon them, until in time they become part of the delta plain. Some delta plains are very large; that of the Nile starts a few kilometers below Cairo and is about 200 kilometers long.

INTERRUPTED ACTIVITIES

The activities of streams may be temporarily interrupted by various accidents. A portion of a valley may be flooded by a lava flow or by a succession of such flows. The lava may dam the valley and impound the stream waters, thus forming a lake. Eventually the water overflows and erodes a channel in the lava; this channel lowers the level of the lake and may cause it to disappear. The products of volcanic explosions—ashes, pumice stone, and so on—produce the same results as lava flows in interrupting stream activities; they settle into river channels and fill them.

Landslides often dam up streams and form lakes. Some of the newly formed barriers are resistant; overflow drainage damages them very little. Others are easily cut into and may be partly or wholly demolished. In some instances, log rafts carried by main streams have dammed up the mouths of tributaries. In certain cases the lakes that have been formed in this way have existed for many years.

STREAM EVOLUTION

Geologists classify streams as young, mature, and old. The age of the stream is not the important factor. The classification is based on the sort of work the stream does and the type of valley it erodes. These factors in turn depend on the elevation and stability of the land, the initial slopes, and the composition and structure of the rocks. Even within a single given region, different streams of roughly the same chronological age may be youthful or old in development.

Young streams and valleys. Young streams carry coarse debris as they head swiftly down more or less steep slopes. They are rarely loaded to capacity with sediment. They downcut vigorously, eroding V-shaped gorges and valleys. The widening of the valleys of young streams is accomplished partly by the attack of the stream upon its banks. However, it is

chiefly due to other erosive agents, which cause loose fragments or masses of rock mantle to slide down the slope. The chief deposits laid down by young streams are bars of gravel and sand.

Mature streams and valleys. As the slope of a stream bed is reduced by continued erosion, downcutting power diminishes. The stream's energy then serves principally to transport sediment and to bring about sideward erosion. Meanders become more prominent and the erosion terrace is widened. A mature stream is loaded with sediment to about its capacity at all times. When this sediment spreads over the terrace, flood plains are formed.

Old streams and valleys. When a stream reaches old age, its downcutting power is negligible. Its activities are limited almost exclusively to transportation of load and sideward erosion. The erosion terrace becomes very wide and is continuous along both sides of the stream. Water spreads over parts of this terrace, causing major floods and leaving layer upon layer of sediment. Flood-plain deposits and erosion terraces are far more extensive than those of mature streams.

In its old age, a stream flows through a low, gently undulating land surface, which is called a *peneplain*. The peneplain consists of erosion terraces and flood plains of old streams and the inconspicuous divides separating the various drainage lines. Here and there, bold eminences appear above the general surface. These heights are called *monadnocks*, after Mount Monadnock, in New Hampshire, which rises from the plain in just this way.

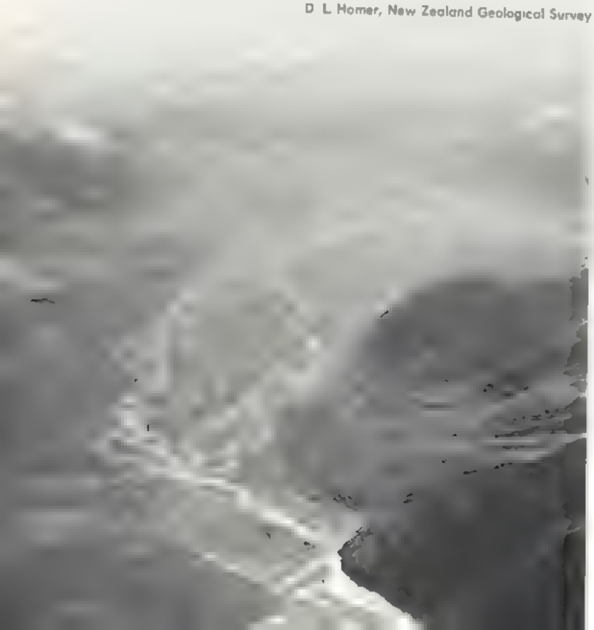
The land areas between valleys undergo their own cycle of erosive development, in association with that of the valleys. The interstream profiles are often the reverse of those of valleys—broad and flat or rounded in youth, narrow and possibly jagged in maturity. This may be explained by the fact that the divides between the streams are usually undergoing more or less constant reduction by erosion as the valleys are extended and broadened at their expense. As the slopes of the divides continue to develop, however, they tend to become more gentle, with the remnants of the old uplands surviving, perhaps, on the heights. Should the general cycle go into extreme old age, which practically never happens, the valley floors and divide slopes may combine to form a gently rolling landscape, with isolated rounded rises here and there representing the old divides. This landscape may resemble the peneplain with monadnocks described above.

Generally speaking, the evolution of streams and valleys is not an orderly progression from youth to old age. For one thing, the titanic forces at work under the crust of the earth may cause the land to be uplifted and tilted. The resulting steep gradients will cause streams to flow with greatly increased velocity and will add to their erosive power. Such streams are said to be rejuvenated, or revived. Rejuvenation may also be brought through changes in climate or destruction of plant cover.

When streams are thus invigorated, they cut youthful V-shaped valleys and in general dissect the surface of the earth like any young stream. Sometimes landscapes representing several rejuvenations are found in the same area. In North America's Appalachian Mountains, for example, there are at least seven distinct landscapes. There are three in California's Sierra Nevada.

The braided channels of the Rangitata River in New Zealand. Streams flowing on soft material often form such small, interwoven channels on easily eroded sand and gravel.

D. L. Homer, New Zealand Geological Survey



Wi... driven sand can deeply scar the face of a cliff and can help to carve some un... rock formations

HOW WIND CHANGES THE LAND

by H. T. U. Smith

Wind is one of the important forces that shape the surface of the earth. Wind erodes rock materials and soil, transports the eroded materials over vast areas, and deposits them upon the earth. In this way wind levels the land here, builds it up there, scoops out hollows, and creates the distinctive types of landscapes that make the earth's surface so richly varied.

One might think that the stronger the wind, the more effective it would be as an agent of erosion, transportation, and deposition. This is not the case. Violent winds, such as tornadoes and hurricanes, are not particularly important as agents of geologic change. They do not come often enough, or stay long enough, or cover a wide enough path to be effective. The more moderate winds that blow for hours at a stretch, time and time again through countless centuries, are far more important than are the more violent types of winds in the never-ending task of altering the surface of the earth

As the winds erode the land, they work with two types of material – sand and dust When the sand is carried by the wind, it drifts along close to the ground until it accumulates in the distinctive hills and ridges known as *dunes*. After the dunes have been formed, they too are moved by the winds

The effects of wind upon dust particles are quite different. The particles are blown high in the air and are transported rapidly and to considerable distances, sometimes traveling more than 1,500 kilometers. Finally they are deposited upon the ground. Dust is spread more thinly than wind-blown sand; it covers a much larger area.

EFFECTS OF WIND EROSION

It may be difficult to point to definite traces of erosion by the wind. Frequently the layer that has been removed is so thin and the area of removal so extensive that the noticeable effects at any one spot are slight. There are some exceptions, however. In certain desert basins in the western United States, the ground level in various limited areas has been lowered as much as five meters by the blowing away of dust. In North Africa some fairly large desert basins, forming oases, have been carved out, at least partly, by the blowing away of sand and dust. In cases like these, erosion by the wind is limited to loose sand, silt, and clay. In other words, the wind picks up only what other processes of erosion have made ready for it.

A special variety of wind erosion, known as *sandblasting*, is produced by blown sand before it is trapped to form a dune. The grains of sand act like tiny chisels, scratching and scraping whatever surface they strike. Each grain cuts a little deeper than the one before. In this way, even hard materials can be gradually ground down. Bottles and pieces of glass lying in areas of drifting sand soon lose their brightness and take on a dull, frosted appearance. If automobiles are driven in sandstorms, their paint may be worn off and their windshields frosted in less than an hour. In some places where sandblasting is especially strong, wooden telephone poles are gradually worn away unless they are protected.

The effect on rocks, which naturally have been exposed to sandblasting for a longer period of time, is much greater. The larger blocks and boulders are grooved and pitted in ways not duplicated by other processes of erosion. If different parts of the rock are of unequal hardness, the softer parts are worn down more rapidly, leaving the harder parts standing out. Pebbles are sometimes worn down to Brazil-nut shape. One or more surfaces may become flattened. Such sandblasted rocks are called *ventifacts*, or objects made by wind. Ventifacts are found in most of the areas where sand is drifting actively today, and in many other regions where wind action was vigorous at one time.

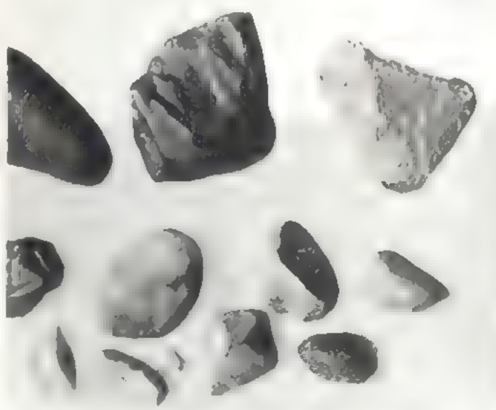
In most places, the effects of sandblasting are confined to scattered blocks and pebbles. In a few regions, however, the bedrock itself has been carved into distinctive ridges, troughs, and unconnected hollows, all on a relatively small scale. This happens only where sandblasting is unusually strong, and where there is practically no rain to permit erosion by running water—a condition found in parts of southwestern Africa.

SAND DUNE AREAS

The sand dunes of the world represent one of the most striking results of wind action. In the United States, dunes are found in a great many widely separated places. Altogether, these dunes cover more than 100,000 square kilometers, or about 1½ per cent of the entire area of the United States. They are far more widespread in other regions of the world. Some of the

Ventifacts are pebbles that have been worn down by the wind. These wind-cut stones are often shaped like Brazil nuts, or flattened on one or more sides.

H T U Smith



dune areas in the deserts of Asia, Africa, and Australia are larger than many dunes found in the United States. Smaller formations are found in many countries that do not have deserts, such as France and Germany.

TRANSVERSE DUNES

There are various kinds of dunes. In some regions, such as the desert area of southern California, the dunes look like great sharp-crested waves in a vast sea of sand. Formations of this kind are called *transverse dunes,* because they lie across the direction in which the wind is blowing. They are more or less curved. Each wave formation is generally broken up by gaps into several sections. Every dune has a steep side and a gentler sloped side. The steep side always faces away from the wind. The sand is blown up the more moderate slope and is dropped at the crest.

As we walk over a transverse dune, we find that the sand is loose and easily moved. Our feet sink in and each step is an effort. We can climb up the gentler slope, but it is more difficult to scale the steep side. If the wind happens to be blowing hard, sand showers down upon us. Suppose that we move to the gentle slope of the next dune. Plenty of sand is blown along here too, but it stays fairly close to the ground. Only when the wind is exceptionally strong does it rise to face level.

Wind-blown sand moves in two different ways. Some grains, especially the larger ones, roll and bounce along, often forming ripples that seem to creep over the surface of the sand. Other grains, however, are swept up into the air and move along in a more or less steady stream. The harder the wind blows, the faster and higher the stream moves, and the more sand is carried. The stream flows smoothly up to the top of the dune. As soon as it passes the crest it loses momentum, drops down out of reach of the wind, and is trapped behind the dunes.

As the wind blows, sand is taken from one side of the dune and added to the other. Therefore, the dune as a whole advances with the wind. The advance continues as long as the wind blows in the same direction. A change in direction will cause a corresponding change in the direction in which the dune will move. If the wind entirely reverses its direction, the dune will do likewise. What was formerly the steep side will become the gentler slope, and vice versa.

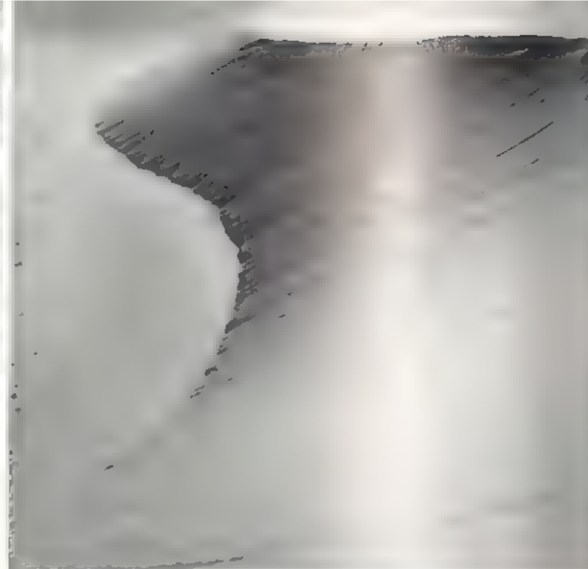
Wooden objects are particularly subject to wearing away by sandblasting. Here a telephone pole is protected by a metal sheet and buffer poles.

Transverse dunes are found in many parts of western North America and also in the deserts of Africa and Asia, including the Middle East. In many of these places, the sand waves are lofty and have long valleys, or troughs, between them. Such dunes may be many meters high, and occasionally may tower to a height of 300 meters or more.

BARCHANS

So far we have been dealing only with the larger transverse dunes on a continuous

Spence Air Photos



Exxon

Two types of dunes. Above: U-shaped dunes along a coastline. Some of these dunes are being gradually buried by sand waves advancing from the seaward side. Right: transverse dunes in Saudi Arabia. These dunes travel in the direction of the wind.

sea of sand. A series of smaller, more regular dunes quite distinctly separated from one another is another type of formation. These dunes are more or less crescent-shaped, with stubby horns pointing in the direction toward which the wind is blowing. Dunes such as these are called *barchans*. Barchans can join together, forming "Siamese twins" and "Siamese triplets." The more symmetrical forms are found only where there is no crowding. Barchans are moved by the wind in much the same way as the larger sand waves. The difference is that some sand is blown around the sides as well as over the top, thus accounting for the horns.

LONGITUDINAL DUNES

In some places the principal forms of dunes are long, low ridges of sand that lie approximately at right angles to the trend of the sand waves, or parallel to the direction of the wind. These large formations are called *longitudinal dunes*. Some of the ridges are practically straight; others are slightly wavy. They range up to about 10 meters in height and 30 meters in width. Many are more than one and one-half kilometers long.

Both sides of these dunes have practically the same slope. The dunes are more or less covered with grass and bushes. Only the crest is bare. On some dunes, even the crest is covered with vegetation. Where this occurs, it means that wind action has stopped on this particular dune. There are many varieties of longitudinal dunes. They occur in true deserts and also in regions where there is scanty vegetation. In some parts of the Sahara they represent the main type of dune. They are also widespread in the deserts of Australia and India. There are interesting longitudinal dune formations in the semidesert plateau region of northeastern Arizona.

U-SHAPED DUNES

There is a fourth type of dune, made up of U-shaped ridges, largely covered with bushy vegetation. In some places bare patches, across which sand is blowing, may be seen at the bend in the U. On these so-called active dunes, there is a steep slope away from the wind, as in barchan dunes, but the horns point in a direction opposite to that of the barchans. This type of dune is found only where vegetation is present. The sides of the U are always at least partly covered with vegetation. In some places there are variations of the U shape because individual dunes have been crowded together, producing forklike or rakelike formations. Here and there U-shaped dunes are gradually being buried by oncoming sand waves. This means that a second series of dunes is being built up upon the older dunes. More than two generations of dunes may be formed in this manner.

U-shaped dunes and similar types are common along sandy shores and other


Spence Air Photos

S[illegible] dunes in southeastern California. In the lower right, individual more-or-les[illegible] crescent-shaped dunes, known as barchans, can be made out.

s[illegible] areas, where grass, bushes, or trees ar[illegible] growing. In North America, they occur at [illegible]any places in the Great Plains, east of th[illegible] Rocky Mountains, where winds are st[illegible]ong, droughts occur frequently, and the g[illegible]ound is very sandy. They are never found i[illegible] true deserts.

B[illegible]OWOUTS

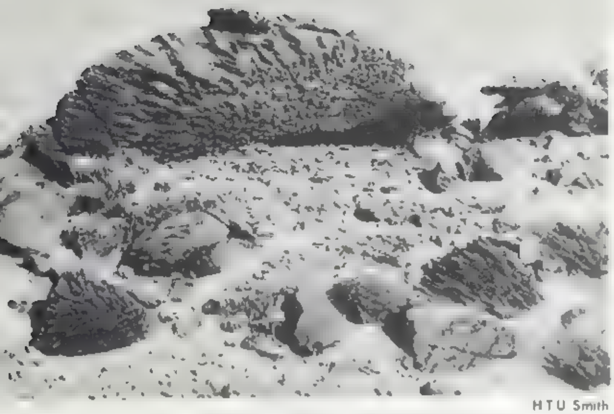
In some dune areas, it is difficult to re[illegible]ognize any distinctive types of dune. [illegible]s is especially true where the formations are largely covered with trees, as along the s[illegible]thern shore of Lake Michigan in North America. From a high vantage point one sees only an irregular pattern of hills and ridges, crossed by long, narrow patches of bare, drifting sand, called *blowouts*. Only the blowouts have a distinctive appearance, showing the effects of present-day wind action. The typical blowout is an elongated, troughlike zone, culminating in a broad apron of sand. The trough is formed by wind erosion – the blowing away of sand. At the end of the trough that is away from the wind, the sand generally forms a steep, high front. As more sand is blown over the top, this front gradually moves forward, burying trees and whatever other obstacles may lie before it. Blowouts gradually bring about a breakdown of older dune masses that have become static.

Irregular, grass-covered sand hills, such as those we have described, are called *dead dunes*. They represent masses of sand that were once shaped by the wind and were then anchored in place by the overgrowth of vegetation. Where blowouts occur, the conflict between grass and drifting sand can be seen today, although on a much smaller scale than before. In some places, the sand drifts fast enough to bury the grass and destroy it. In other areas, certain kinds of grass grow fast enough to escape burial, and they stop the drifting sand.

Transverse dunes, barchans, longitudinal dunes, and U-shaped dunes are all referred to as live, as long as they undergo the action of the wind. They can all become dead if they are invaded by vegetation. As dead dunes, they will no longer be subjected to the effects of wind action. If the vegetation is destroyed, wind action may be revived, leading to changes in the dune.

DUNES MOVE

All live dunes have the property of movement, either of the entire dune or part of it. The rate of movement depends on the strength and frequency of windstorms, the constancy of wind direction, and the size of the dune. Generally, the larger the dune, the slower it moves. The rates of movement range from a meter or so to more than thirty



HTU Smith

Boulders showing the remarkable grooving and pitting effects that are produced by sandblasting over a long period of time.

meters per year. The average is probably less than 30 meters. Where strong winds blow regularly in the same direction, large dunes can override and bury whatever lies in their path. Farm land, forests, roads, buildings, even entire villages may be overwhelmed. Sooner or later, however, most dunes are anchored by vegetation.

DUST STORMS

Dust storms are a vivid memory to those who lived in the Great Plains area of the United States in 1933 and in the years following. While these storms were raging, the air was filled with choking dust. Sometimes it swept forward—a great, high cloud with a steep front. Anyone overtaken by such a storm would suddenly find themselves gasping amid swirling clouds of dust particles. During severe dust storms, day became as dark as night. Automobile headlights could be seen only at a distance of a couple of meters. Breathing was difficult and practically all outdoor activity came to a halt.

After a storm had passed, dust was left everywhere. It was a fine, powdery substance that penetrated even into tightly closed buildings. If the storm had been mild, the dust residue was only a thin, gritty film. If the storm had been unusually severe, it left behind layers of dirt that could be removed by the shovelful.

The air would often be hazy with dust hundreds of kilometers from the starting point of a storm. Sometimes a thin layer of brownish dust would be deposited more than 1,500 kilometers away from the point of origin. The layer would be particularly noticeable if it fell on snow. A typical storm, in November 1933, was traced from the Great Plains to northern New York, a distance of over 2,000 kilometers. It traveled at an average speed of 70 kilometers per hour.

The amount of dust carried and deposited by a single storm was enormous. At moderate distances from the starting point, up to 14 metric tons of dust per square kilometer were deposited. At greater distances, the deposits were not so heavy, of course; yet they amounted to one metric ton per square kilometer in some instances. Since the dust storms raged over tens of thousands of square kilometers and extended over a period of several years, the total amount of dust laid down came to millions of metric tons.

The dust carried in this way had been blown from farms in which the soil had become dry, powdery, and bare. For a long time there had been too little [illegible]rops had failed to grow, leaving the [illegible]d unprotected from the wind. In man[illegible]es, in a desperate attempt to start new [illegible]ps, the dry ground had been broken up [illegible]arming implements into a crumbly mass. As strong winds swept over this bare, loose earth, the finer material was stirred by gusts and eddies and carried away. The coarser material was blown along the ground, scraping loose more dust for the wind to pick up. Once in the air, the dust was kept continually stirred up by swirling air currents. Only when the wind died down, or when it encountered obstacles such as buildings, was this stirring process checked. The dust then settled down gradually.

The dust storms that we have described resulted from temporary, man-made deserts. The conditions under which they occurred have been duplicated again and again in widely separated regions of the world, and have led to the devastation of immense areas. Improved farming techniques should, however, help prevent such conditions from again occurring.

DUST AND SPECIAL ENVIRONMENTS

The dust storms that have a particularly important bearing upon geologic change occur particularly in two types of environment: in true deserts and in the vicinity of glaciers.

In true deserts, there is no vegetation to protect the ground. The wind sweeps unchecked over bare earth and stirs up any fine material that is present. Severe dust storms are common. Frequently the dust is blown long distances beyond the borders of the desert. Showers of reddish dust from the Sahara have long been familiar in southern Europe. They have penetrated as far north as England. One of these dust falls, in 1901, left from one to ten metric tons of dust per square kilometer over an area of at least 800,000 square kilometers, making a total deposit of some 1,800,000 metric tons in Europe alone. It is estimated that an average thickness of about 15 centimeters has been added to the soil of Europe in the last 3,000 years by dust storms originating in the deserts of Africa. A similar story could be told of other deserts.

In the vicinity of glaciers, too, conditions favor the rise of dust storms. Glaciers carry much ground-up rock material secured from their rocky channels. During the melting season, running water transports this drift along broad outwash channels away from the glacier. After the melting season, the channels become dry. The channels then contain large amounts of rock flour, or ground-up rock. This powdery material is easily picked up by winds blowing out from the ice, and local dust storms result. As the winds slow down away from the ice, the dust settles out, collects around vegetation, and in time becomes a part of the soil. It may gradually collect to a thickness of many centimeters to more than a meter, covering the ground like a blanket. Fairly rapid deposition of this type takes place near the glaciers of Alaska and Greenland.

LOESS

If a deposit of wind-blown dust is thick enough and distinctive enough to be easily recognized, it is known as *loess* (pronounced *loh'-ess* or *luhss*). This formation generally shows no horizontal layering or bedding. It occurs in a single vast layer. The thickness of the deposits ranges from a meter or so to more than thirty meters. In some areas of China there are deposits over 100 meters high. Loess sometimes forms high bluffs along the sides of valleys. When these deposits are eroded by running water, a distinctive landscape is formed: nearly vertical walls alternate with flat-bottomed valleys and gulleys, forming an intricate pattern.

The dust particles of which loess is composed are well sorted. They consist of grains between $\frac{1}{16}$ and $\frac{1}{32}$ of a millimeter in diameter. Fossils found in loess are mostly the shells of land snails and the bones of land animals.

Loess deposits dating back to the glacial period are widespread in the central and northwestern parts of the United States. Extensive loess deposits also occur in South America, Asia, and Europe. In some parts of China, thousands of people live in cavelike dwellings dug into bluffs of loess. Some Chinese loess deposits show the layering that is generally associated with deposits laid down by water, thus suggesting that running water finished what the wind began.

A blowout. Winds blowing from the lake have cut through an older dune that was static. The grass-covered dunes that remain are called dead dunes

DEPOSITION OF VOLCANIC ASH

The eruptions of active volcanoes provide a special source of dust for the wind to move. This material, which is called *volcanic ash*, is blasted violently into the air. It reaches far greater heights and is present in far greater quantities than ordinary dust. It is carried farther and is deposited in thicker layers. When Katmai Volcano, in Alaska, erupted in 1912, volcanic ash fell like snow at the village of Kodiak, about 160 kilometers from the volcano. It covered the ground to a depth of nearly thirty centimeters. The clouds of ash were so dense that they brought almost continuous darkness for more than two days. After the ash had settled down, it was carried like snow by the wind, and was stirred into minor dust storms.

Other regions were similarly affected. It is estimated that a mantle of ash more than thirty centimeters covered an area of 5,000 square kilometers. The ash mantle was more than six millimeters thick over an area of more than 50,000 square kilometers. Some ash fell as far as 1,400 kilometers away from Katmai Volcano. The presence of volcanic dust in the air was reported from North Africa.

When the island volcano of Krakatoa, in Indonesia, exploded in 1883, volcanic ash fell many centimeters deep nearly 1,500 kilometers from the scene of the explosion. Some ash was deposited as far away as Holland. Quantities of volcanic dust were carried around the world. These atmospheric dust particles caused unusually brilliant sunsets in many areas.

It has been estimated that hundreds of cubic kilometers of volcanic ash have been blown into the air and spread out over the earth's surface within the comparatively brief span of time covered by historical records. This, however, is but a trifling amount compared to the enormously greater volume of dust that was transported and deposited on the earth's surface during the preceding millions of years.

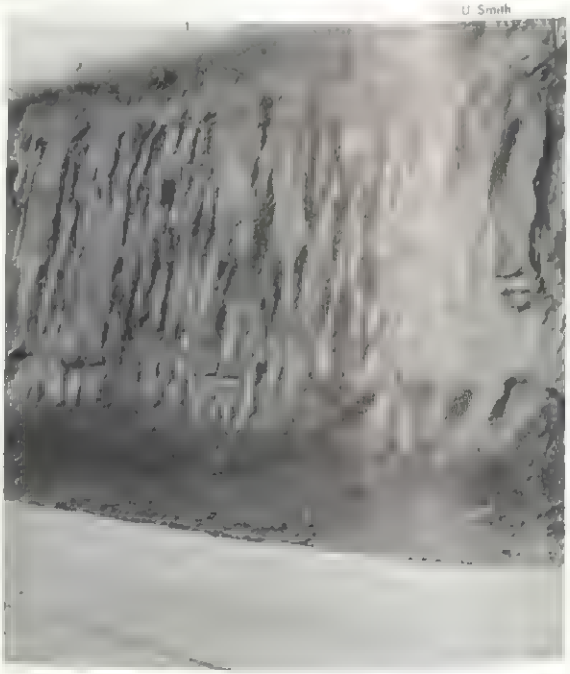
A great deal of volcanic ash falls on land, remains where it falls, and becomes a part of the soil. It acts as a natural fertilizer, adding chemical elements needed by growing plants. A few years after the eruption of Katmai Volcano, the vegetation in the vicinity grew better than ever before. In some parts of the world the soil would be very poor indeed if it were not for the repeated additions of volcanic ash.

A certain amount of ash is carried away by the wind, or washed away by running water. Sooner or later, much of it finds its way into streams and lakes, where it forms extensive deposits. Some of these deposits are so thick and contain so much pure ash that they have been commercially exploited as a source of scouring powder and for other purposes.

Some volcanic ash falls directly into the sea. To this is added the ash that has been washed down from the land by running water. In the course of long ages such deposits have formed distinct layers of sedimentary rock, known as tuff and bentonite. Rocks of this type, formed at various periods of the earth's history, have been found in many places.

A thick deposit of wind-blown dust is known as loess. Loess sometimes forms high walls along the sides of valleys.

U Smith



THE WATER SUPPLY

by William S. Foster

What is water? To the scientist it is the compound H_2O, combining two atoms of hydrogen with one of oxygen. It can take the form of a solid, liquid, or gas. At atmospheric pressure (1 kilogram per square centimeter), it solidifies when cooled to 0° Celsius; it boils at 100° Celsius. When pure, it is neither acid nor alkali. Water dissolves many substances. It is itself decomposed into its two constituents, hydrogen and oxygen, at 2,500° Celsius and at ordinary temperatures when an electric current is passed through it.

The sanitary engineer sees water from a different viewpoint. He is interested particularly in the liquid form of water. The liquid must be transported from its source to homes, offices, factories, and other places where it is to be used. It must be kept free from harmful bacteria. It should be colorless, relatively odorless, tasteless, and moderately soft, or free from mineral salts. Waterworks scientists think of ice—water in its solid form—as a nuisance, causing trouble to river intakes, pipelines, and hydrants. They consider water vapor only as water that has been lost from their reservoirs.

From the viewpoint of the public, water is an absolutely essential commodity. It makes up roughly 70 per cent of the total weight of our bodies. It must be replenished constantly as it evaporates from the lungs and skin and passes out of the body in the form of wastes. If we were denied water for a few days, we would die of dehydration. Water is also essential for our industries, which use vast quantities. For example, about 80 metric tons of this liquid are used in the manufacture of a metric ton of ingot steel. It requires 190 more metric tons of water to turn this metric ton of ingot steel into fabricated products.

HISTORICAL REFERENCES

Water dominates our history. The ancient Egyptians constructed an extensive system of reservoirs, storing up the waters of the Nile. There are many references to water supply in the Bible. For example, the 26th chapter of Genesis tells how Isaac's herdsmen fought with the inhabitants of the valley of Gerar for the possession of wells in the valley. Much later King Hezekiah "made a pool and conduit and brought water into the city of Jerusalem" (II Kings: 20, 20). Ancient Rome probably would never have attained its greatness without the assistance of its waterworks engineers. The waters of the Tiber had become too polluted to serve for drinking purposes. The engineers constructed nearly 650 kilometers of aqueducts, which brought water into the city from various outside sources. In Arizona and New Mexico, archaeologists still explore irrigation projects built by ancient North American Indian engineers.

Few of us stop to think about the water we drink. Before the water reaches this fountain, it must undergo purification processes

American Water Works Association

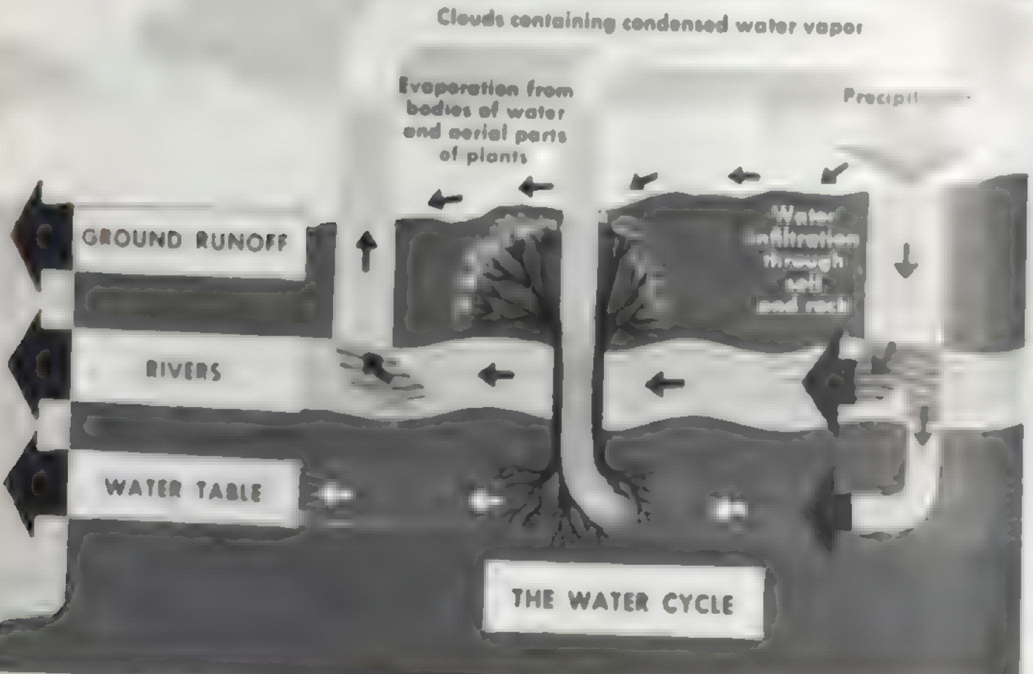
EARLY WATER TREATMENT

The treatment of water goes back to antiquity. Aluminum sulfate, a useful chemical coagulating agent, was employed by the ancient Chinese and Egyptians. A medical book written in Sanskrit, the written language of ancient India, probably about 2000 B.C., pointed out that "it is good to keep water in copper vessels, to expose it to sunlight and to filter it through charcoal."

However, the distribution and treatment of water as we know it today is a modern development. Until comparatively recent times, only the extremely wealthy could afford to have water distributed to their houses. Most people were forced to carry it in containers from wells, or springs, or central distribution points. House-to-house distribution became possible only through the development of steam-driven pumping machinery and cast-iron pipe strong enough to withstand h[illegible]ernal pressures. Modern water tr[illegible]an with the development of the [illegible] filter by James Simpson in England [illegible] The turn of the century saw the [illegible]tion of the rapid sand filter, wh[illegible] the slow sand filter almost obsol[illegible] shall discuss both types of filters la[illegible] this article.

SOURCES OF OUR WATER

Water passes through a [illegible]ned hydrological cycle, or water [illegible]alls to the earth's surface in the fo[illegible] or some other form of precipitat[illegible] of it soaks into the ground, is abs[illegible]ant life, and is returned to the at[illegible] by transpiration from the aerial [illegible]nts. Some of the precipitation [illegible]gh permeable and porous rock[illegible]nes part of the ground-water su[illegible]nd water makes its way to rive[illegible] to



the surface in springs. Sometimes it is brought to the surface by wells.

A good deal of the water that is precipitated flows along the surface of the ground in streams, large and small, or is collected in ponds and lakes. Much of this water is returned to the ocean. The sun draws surface water to the clouds by evaporation. From the clouds it is precipitated to the earth, and another cycle begins.

In the hydrological cycle, therefore, water passes from the atmosphere to the earth and then back again to the atmosphere. To obtain water for our water supply systems we must draw it from rivers or lakes, or from wells which tap the ground water beneath the surface.

When water is drawn from a river or other stream, the engineer must decide whether the river, when its level is lowest, will meet the maximum demands of the community. The heat of summer will reduce the stream by evaporation. At the same time it will increase the use of water for lawn sprinkling, air conditioning and other purposes. Suppose the engineer determines that the community will use more water than the river can supply during low periods. He will arrange to store a portion of the water when the river is high by building a dam in the stream. The water that collects back of this dam will form an *impounding, or water-collecting, reservoir.*

If the dam has been correctly designed, the water level in the impounding reservoir will be low before the spring overflow occurs. The reservoir, therefore, will be able to catch and store the excess water that the overflows bring. As the summer goes on, the community will draw on this reservoir to compensate for the lack of adequate flow in the river.

PROBLEMS OF RESERVOIRS

Many problems arise from the use of impounding reservoirs. For example, in most parts of the United States the law does not permit a city to impound and use all of the water of a stream. The law protects the rights of those living downstream to a part of the water. [illegible] has to enter into an agreement [illegible] concerning the amount of water that can be taken from a river and [illegible].

[illegible]

[illegible]

[illegible] supply system through *intake works*. In reservoirs using earth dams, an intake tower is located away from the dam. The tower is equipped with a series of ports [illegible]. Water flows through the ports into the intake supply [illegible]. If the water is impounded by a [illegible], the [illegible] can be built [illegible] itself.

Coarse screens are generally placed in the [illegible] to keep large floating [illegible] from [illegible]. [illegible] cleaning devices are often used.

[illegible]

Many of our streams carry silt washed from the soil. This silt often causes trouble to dams and reservoirs. In 1893 a reservoir was built across the Colorado River at Austin, Texas, with a capacity of [illegible] water. [illegible] later its capacity had been reduced to [illegible] because of silt [illegible].

There are several ways of meeting this problem. Dredging is one; the use of silting basins is another. Silting basins receive the water before it goes to the reservoir and trap the silt it contains. Of course the basins must be dredged from time to time to remove the silt. A third method is the use of low-level sluice gates, through which silt flushes out of the reservoir during times of flood. Sluice gates of this kind are not particularly useful on the larger types of reservoirs. A fourth method is to draw in clearer water from offshore areas by means of long intakes. This is no longer practiced very much.

THE PROBLEM OF EVAPORATION

Evaporation causes open reservoirs to lose a great deal of water. This is particularly true in hot, dry areas, such as the southwestern United States, where the need for water is great. For example, Lake Sahuaro, in Arizona, covering some 600 hectares, will lose as much as one and one-half meters of water to evaporation during the year. Lake Hefner, covering 1,000 hectares, and supplying Oklahoma City, Oklahoma, with water, will lose more than one-half of a meter of water during the hot months of June, July, and August. When we learn that there are 10,000,000 liters of water in one hectare/meter (one hectare one meter deep), we realize the tremendous volume of water that is involved here.

Progress has been made in solving the problem of loss of water from reservoirs by evaporation. To cut down such water loss, investigators have developed a thin chemical film, consisting of a mixture of hexadecanol and octadecanol. The film, only one molecule thick, floats on the surface of the water and makes it harder for water molecules to escape into the air. If the film is dispersed by wind, it forms again. Tests at Lake Sahuaro by the U.S. Department of the Interior have indicated a reduction of almost 15 per cent in evaporation. Even better results have been attained in tests conducted by Oklahoma City officials at Lake Hefner.

By inhibiting evaporation, the film causes the temperature of the water to rise somewhat and so stores the energy radiated into the water by the sun. Studies show that the film does not affect the physical and chemical qualities of the water nor harm the wildlife it contains.

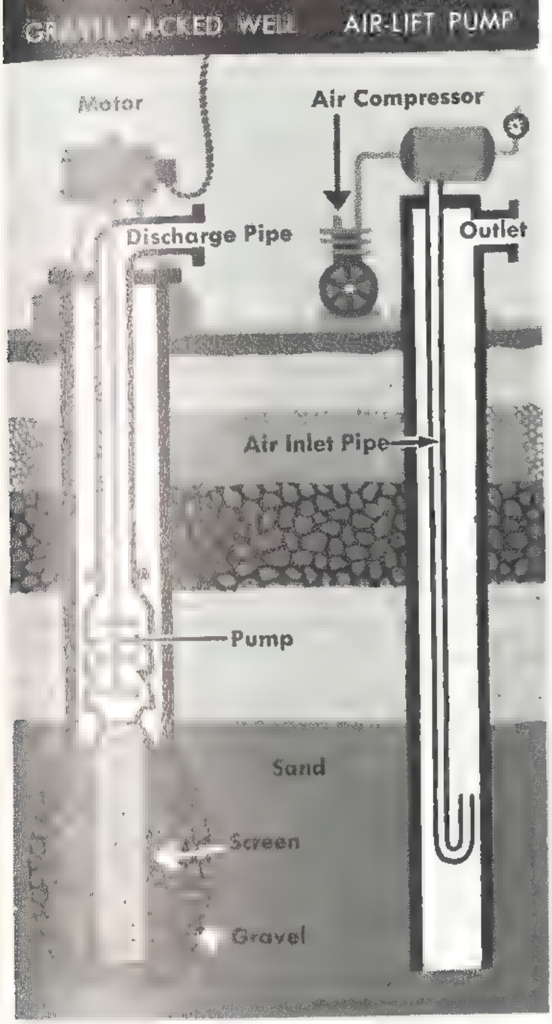
TYPES OF WELLS

A considerable part of the water supply is derived from ground water, which is contained in the openings of the soil and rock under the surface of the earth. To make this ground water available for water-supply systems, wells must be drilled, driven, or even dug.

If we need only a relatively shallow well in soft material, we can drill it by hand or by power-driven augers. Most wells, however, are dug by cable-, or drop-tool, drilling machines. These consist of a tower, a motor, and a large walking beam, or lever that swings up and down about a pivot. A rope or cable carrying the drill passes from one end of the walking beam over a pulley at the top of the tower and then down into the well. The motor then rocks the beam about the pivot, lifting and dropping the heavy drill. The operator does not allow the drill to drop freely to the bottom of the well. Instead, he lets the rope catch the drill near the bottom of the excavation. As the drill hits bottom, it stretches the rope and then springs back because of the rope's tension. The operator feeds out rope gradually as the hole becomes deeper.

Special conditions may require other types of drilling operations. For example, the California, or stovepipe, method is used to drill through gravel and loose rock materials. The operator uses a series of pipes, ranging from 20 to 90 centimeters in diameter, depending upon the size of the well to be built. These pipes come in short lengths. They are telescoped like pieces of old-fashioned stovepipe as they go down. A small sand bucket, or bailer, is dropped down the piping. As the bailer scoops up sand and gravel, the pipe sinks deeper.

For drilling deep wells in consolidated, or hardened, rock formations, the hydraulic rotary method is preferred. This consists of rapidly rotating a bit on the bottom of a string of drill pipe. A mud fluid descending



Two types of wells. Left: a gravel-packed well with a turbine pump. The pump, operated by a motor at the surface, is at the lower end of the discharge pipe, through which water is brought to the surface. Right: a well with an air-lift pump. Compressed air is conveyed through an inlet pipe to the bottom of the well. The air-and-water mixture forming at the bottom is lighter than water; it floats up the well and into a reservoir.

through the drill pipe and ascending outside the pipe removes the cuttings produced by the bit. The pressure the mud exerts on the walls of the hole prevents them from collapsing. The mud also cools and lubricates the drill.

Drilled wells are enclosed with an impervious casing, with a tubular "screen" at the end to allow the entry of water from *aquifers*, or water-bearing strata. A screen of this type consists of slotted cylinders of durable metal. Often the outside of the screen is packed with gravel, a very permeable material, to increase the amount of water flowing into the well. This is called a gravel-wall, or gravel-packed, well.

In some cases, a well is excavated by means of a pointed pipe driven into the ground to the depth of the water-bearing stratum. This is called a driven well. It is not practical to dig such wells to a depth greater than about 25 meters.

A large shaft has to be dug in the construction of the so-called radial well. The shaft has to be extended far enough down in order to intercept the most productive aquifer. From this shaft, a number of driven wells are extended in a horizontal direction. Heavy hydraulic jacks force these wells into place, driving them as far as 60 or 65 meters into the aquifer. Under favorable conditions, the yield from such wells is very large.

Infiltration galleries are also used to capture ground water. These galleries consist of long pipes, laid through a water-bearing stratum that is often fed by streams. These pipes are laid like a huge drain tile, with the joints slightly open. The city of Des Moines, in Iowa, has a remarkable installation of this kind.

PUMPING MECHANISMS

A centrifugal type of pump is often used to draw water from wells. This is known as a vertical turbine pump. It consists of a set of wheels, called impellers, mounted on a long shaft that extends into the well. The impellers rotate as the shaft turns. Water entering the center of the rotating impellers is forced upward and enters the pipeline. Generally an electric motor in the pumphouse at the top operates the shaft.

It is not necessary to use a long shaft, however. Engineers have developed a small, powerful, completely sealed motor, which can operate the pump even when it is submerged. Wells with this type of pump and motor have many advantages. Since they require no pumphouse, there is no danger of stoppage because of flooded pumphouses. The wells will provide water even after an earthquake has struck.

A very simple pump used to draw water from wells is the air lift. This consists of a fairly large pipe called an eductor, which fits inside the well casing. Set within the eductor is a smaller pipe, which is used to convey compressed air to the bottom of the eductor. The mixture of air and water that forms at the bottom is much lighter than water itself. It floats up the eductor pipe and finally out into the pipeline or reservoir. This type of pump has the advantage of operating without any moving parts submerged in water. It also serves to aerate water. The eductor can draw water from practically any type of well hole, even if it is not straight. Its main disadvantage is that its efficiency is low, especially in deep wells.

Other types of pumps, such as the familiar lift pump, are used primarily on very small farms. The lift pump depends upon atmospheric pressure for its operation. It cannot raise water higher than 10 meters under ideal conditions. As a matter of fact, the limit is generally from 6 to 8 meters.

HOW WATER IS TRANSMITTED

Very often a community has to obtain its water from a distant source. The water supply of Boston, Massachusetts, is derived from a lake 80 kilometers from the city. New York City gets over half of its water from the Catskill Mountains, more than 150 kilometers away. Los Angeles goes all the way to Parker Dam—a distance of almost 400 kilometers—for part of its water supply. Cities such as these have much the same problems as the old Roman engineers faced when they built the aqueducts leading into the city of Rome. Of course the modern engineer has much better materials at his disposal.

The connecting links between the water source and the distribution system consist of *aqueducts*, also called *transmission mains*. The water in most aqueducts flows by gravity. In such structures the slope down which the water runs, called the *hydraulic gradient*, must be steep enough so that there will be a continuous flow. It must not be so steep as to bring about excessive pressures. In some cases siphons carry water over mountains, under rivers, and across valleys. Pumps may force the water through the transmission mains in places where it will not flow by the force of gravity.

Water-transmission lines usually take the form of closed conduits or pipes, although in certain cases open flumes are used. Generally engineers do not like open flumes for water-supply purposes because of the danger of contamination.

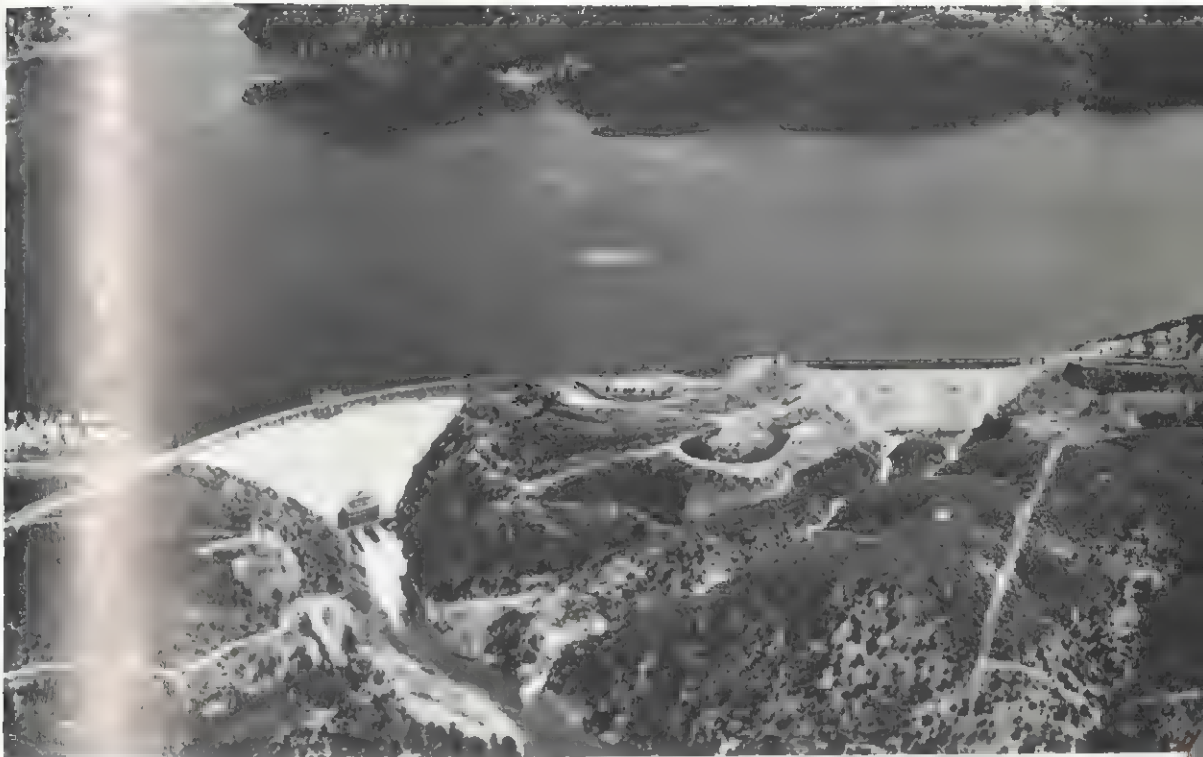
To carry water efficiently, the transmission main should offer the smallest amount of surface for the volume of water carried. Obviously a circular pipe answers this requirement best. In large sizes, however, such piping is very expensive. In such cases engineers often select the more easily constructed type with a cross section suggesting the shape of a horseshoe

Concrete pipe makes a good conduit because of its smooth interior surface. To enable it to carry water under pressure, it is often prestressed. Very strong wire is wound tightly around the concrete pipe and then concrete mortar is sprayed with a pneumatic gun onto this wire-wound core. This keeps the inner core in compression. When water enters the pipe under pressure, the strong steel wires carry the load instead of the concrete.

Another fine material for transmission mains is cast iron. It has a long life, requires little maintenance, and can be cast to withstand heavy pressures. Difficulties may arise if corrosive water is sent through an untreated cast-iron pipe. These difficulties can be overcome by providing an inner lining of cement or bitumen.

Steel pipe can withstand high pressures. Expansion joints must often be provided to accommodate changes in water pressure. Generally the steel is protected by inside and outside linings. Engineers have learned how to make good pipe of asbestos and cement. Pipe of this kind is smooth, withstands corrosion, and is easily installed.

Occasionally transmission mains are made of wood slats bound together by iron bands. Pipe of this kind is so smooth that it offers little resistance to water flow. It will



East Bay Municipal Utility District

Water th[illegible] be used by the members of several communities is often stored in a reser[illegible]eams carry water into the reservoir and the water is held in place by a dam. From here, it is sent for purification and distribution.

not require much maintenance if the wood remains wet and the bands are protected. Cities in Alaska often use this sort of transmission main.

PURIFYING SURFACE WATERS

Once water has been collected, it must be made safe for use in our communities. Sanitary engineers take no chances. They remove from the water everything that they even suspect may be harmful. Their most reliable index of pollution is the coliform bacterium *Escherichia coli.* This bacterium is associated with human body wastes from the colon, a part of the large intestine. Engineers know that the coliform bacterium is not necessarily harmful in itself. However, where it exists, harmful bacteria can also exist. At the same time that we eliminate *Escherichia coli,* we also do away with harmful bacteria.

We pointed out that there are two sources of water—surface supplies and ground-water supplies. The treatment of water will depend to some extent on which source we use. Let us see first how surface waters are treated.

REMOVAL OF ALGAE

Whenever water is stored in surface reservoirs, we face the problem of the plants called algae, which may cause water to acquire an objectionable taste. It is true that certain algae impart to water a flavor suggesting that of watermelon. However, when we drink water, we usually do not want it to have any taste or odor, no matter how pleasant it may be. Hence the waterworks scientist tries to remove algae from the water supply.

The algae found in reservoirs are minute cellular organisms. Most of them have the beneficial effect of introducing oxygen into the water. They also reduce the carbon

dioxide content. However, these plants are quite short-lived. After their death their bodies decompose and create difficult water-treating problems.

Waterworks scientists combat algae by introducing the chemical copper sulfate into the water in minute quantities throughout the year. This is generally done by putting crystals of the chemical in a gunny sack and towing the sack around the reservoir behind a boat. The copper sulfate treatment kills the algae before they grow numerous enough to cause trouble.

In a small reservoir, the growth of algae is checked by covering the reservoir. Algae cannot survive this treatment, since they need sunlight to live. Occasionally algae have been eliminated by a heavy dose of activated carbon. This darkens the water and blots out the sun.

SLOW FILTRATION

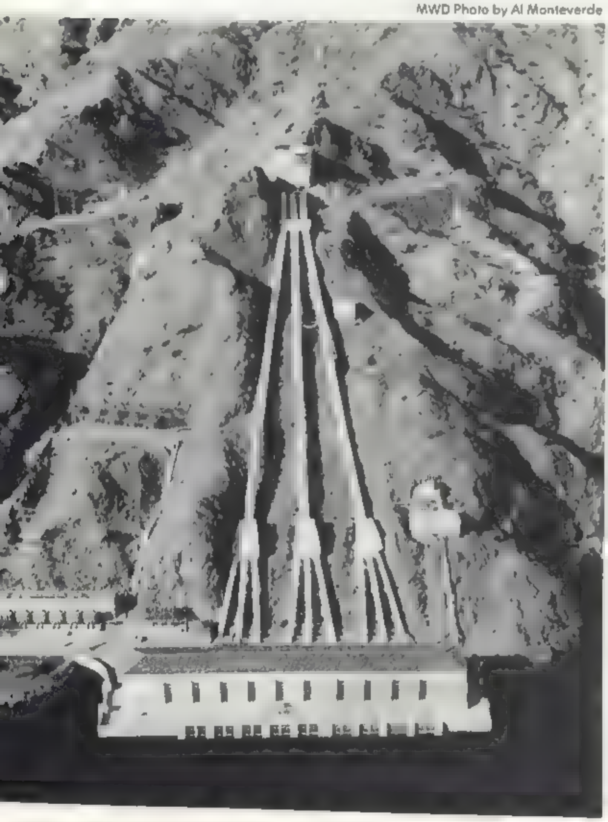
Although algae give water a bad taste,

East Bay

In this mixing basin, water is combined with a coagulant to form floc. The floc attracts sediment suspended in the water and causes it to settle out

Intake pumping station. This facility pumps water from the reservoir into large pipes. The water is then sent to a treatment plant.

MWD Photo by Al Monteverde



they are not harmful. It is particularly important to remove disease-causing bacteria. The slow sand filter process was the first to be used for this purpose. It has been replaced by the more efficient rapid sand filter method for most water-supply requirements.

The slow sand filter works well enough. In this method, water is run into a large basin. The filter consists of a 60- to 90-centimeter layer of relatively fine sand laid on top of a layer of gravel. As the water sinks through the sand and gravel, suspended particles settle on the top layer of the sand, forming a *schmutzdecke*, or *slime mat*, which acts as a filter. The schmutzdecke becomes thickly matted after a time and is removed.

The slow sand filters still in operation do an excellent job. They treat water at an average rate of 20,000,000 to 40,000,000 liters a day per hectare of filter bed. There are certain objections to these filters, how-

East Bay Municipal Utility District

Combined floc and sediment are allowed to drop from the water. This is done in a settling basin. Settling is completed in one to six hours.

ever. For one thing, they are not particularly effective in treating water that contains more than a hundred parts per million of silt or other suspended solids. Sanitary engineers often use the term "parts per million," referring to the ratio between a given substance and the water in which it is contained. When we say "a hundred parts per million of silt," we mean a million liters of water contain a hundred liters of silt. The removal of the schmutzdecke is a slow and expensive process. Workmen have to skim it off with shovels, rakes, and other tools.

Today almost all water-filter plants use the rapid sand filter. This device represents only one stage in a series of treatment processes. Much of the objectionable matter has already been removed by other processes before water passes through the rapid sand filter.

CHLORINATION AND AERATION

The first phase of water treatment is chlorination—the addition of chlorine. Like oxygen, chlorine is a chemically active gas that readily combines with many other kinds of substances, forming different compounds. Waterworks scientists use chlorine for two primary purposes—to kill harmful bacteria and to destroy objectionable organic matter. In a surface supply of water, this organic material may come from dead leaves, algae cells, human refuse, dilute amounts of sewage, and various other sources.

In large water-supply systems, chlorine is normally fed to the water as a gas. Many times the taste that appears so objectionable in chlorinated water is not from the chlorine but from partially altered inorganic and organic compounds. These compounds can be eliminated by increasing the chlorine dosage.

Offensive tastes and odors are often removed by aerating surface water—that is, by mixing it thoroughly with air. The oxygen in the latter combines with, or oxidizes, the various materials in the water that may cause the foulness. We usually aerate water by letting it flow over steps or spray out of nozzles like a fountain. Often water is allowed to trickle over trays filled with coke. This helps absorb any objectionable odors. Aeration is particularly effective in eliminating disagreeable tastes and odors when these are caused by gases formed as organic matter decomposes. Water from wells can also be improved by aeration, particularly if it contains carbon dioxide, hydrogen sulfide, or iron. Aeration releases the carbon dioxide and hydrogen sulfide. It oxidizes the iron, causing it to precipitate as an insoluble compound that filters later can remove.

COAGULATION

The next important step in the purification of water is to mix it with chemicals so as to form *flocculence*, or *floc*—a light, loose mass that will combine with impurities and precipitate with them. The more solid kinds of impurities, such as sediment, are usually removed in this way. Flocculating chemicals of this type are called *coagulants*. The coagulant most generally used

today is aluminum sulfate, or alum. If it is dissolved in water and is given time to react, the alum produces an aluminum floc, which looks very much like a large snowflake. The floc is sticky and carries an electrical charge opposite that of the sediment. Therefore, it attracts the sediment. Later, in the settling basin, the combined floc and sediment will drop to the bottom of the basin and will be removed.

At the same time that a floc is formed, a weak form of sulfuric acid is produced. Generally, there is enough alkalinity to neutralize this acid. If not, lime or soda must be added to the water in order to make it fit to drink.

Other coagulants besides aluminum sulfate are quite effective. Among these are ferric sulfate and ferric chloride, which react to form an iron-hydroxide floc. They also release an acid that can be neutralized.

USE OF CHARCOAL FILTERS

In most water-treatment plants activated carbon is added to the water together with the chemicals that serve as coagulants. Activated carbon is not used as a coa[illegible]lant but to absorb offensive tastes and [illegible]. It is later removed by the rapid san[illegible]ter, together with the combined floc [illegible] sediment. In small plants, water ma[illegible] run through a filter of carbon. This will [illegible]me exhausted in time and will have t[illegible] replaced.

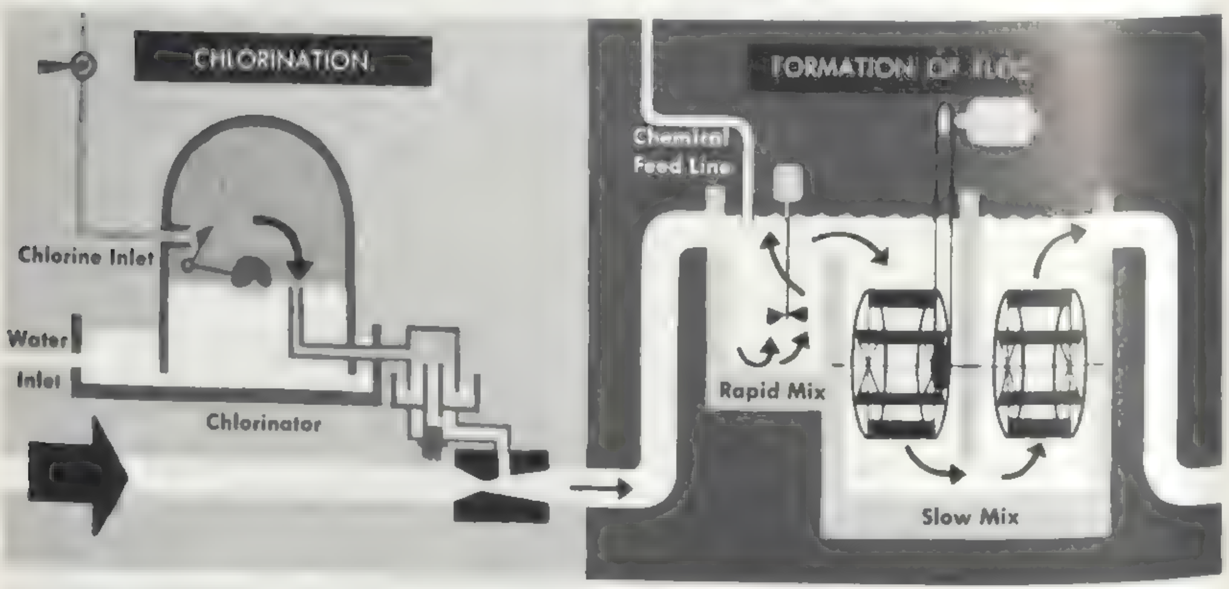
After coagulants have been [illegible] to the water, they must have time to [illegible] and to form a floc. This is done by pa[illegible] the water through a mixing basin. Som[illegible]ns consist of tanks provided with [illegible]. These are plates that deflect th[illegible], forcing it from one side of the tan[illegible] the other, as it passes through. Certain [illegible] basins use mechanical mixing padd[illegible] and propellers in order to stir the wa[illegible]oughly and thus bring about the [illegible] chemical reactions.

SETTLING BASINS

When the mixing operation ha[illegible] completed, water is led into settlin[illegible]. Here the sediment contained in the [illegible] is allowed to sink to the bottom. Water [illegible]

The diagrams on these pages show the steps in water treatment. First, the water is mixed with chlorine. The concentrated solution formed in this manner is then fed into a mixing basin.

Water is mixed with chemicals, called coa[illegible] in such a way as to form a floc—a light, loo[illegible] that will combine with impurities and pre[illegible] with them.



in these basins from an hour and a half to six hours, according to the needs of a particular plant. The capacity of the basin will depend on the quantity of water that the plant treats every day. If this quantity is 900,000 liters, 37,500 liters will have to be treated in a single hour. If you want a settling tank that will keep the water for two hours, you must make it large enough to hold 75,000 liters.

Sediment is sometimes removed in another type of basin—the upflow, suspended-solids contact unit. Water, mixed with coagulating chemicals, enters the lower part of the basin. As it flows upward, it passes through a layer of suspended flocculent material. The fresh chemical reacts more readily in the presence of this blanket. The sediment and floc are filtered instead of settling to the bottom.

RAPID FILTRATION

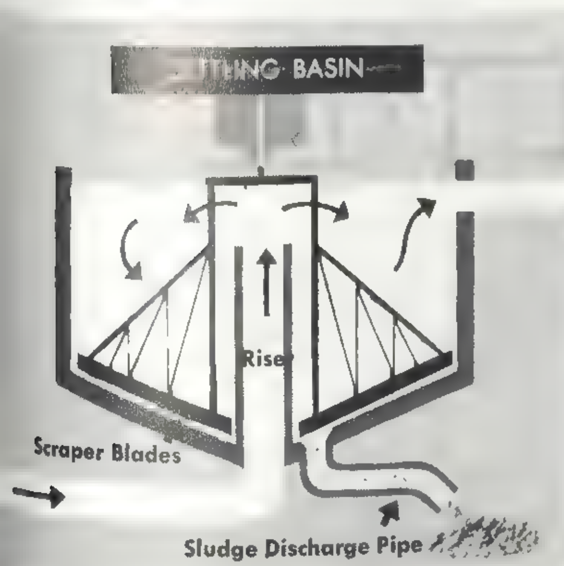
The water is now ready for the rapid sand filter. By this time most of the undesirable matter in the water has been removed. The filter simply puts the finishing touches on the operation. It retains any suspended matter that may not have settled out. Obviously water can pass through this kind of filter much faster than it does through the slow sand filter, which receives untreated water.

Comparatively coarse sand is used in the rapid sand filter. It is usually set 75 centimeters deep upon a layer of gravel. The gravel particles range in diameter from about 2 to 75 millimeters. The larger sizes are at the bottom. After the water has passed through the sand and gravel, it is drained off through pipes. The sand in the filter can be replaced by finely ground anthracite coal. Many feel it does a better job. However, sand is generally cheaper.

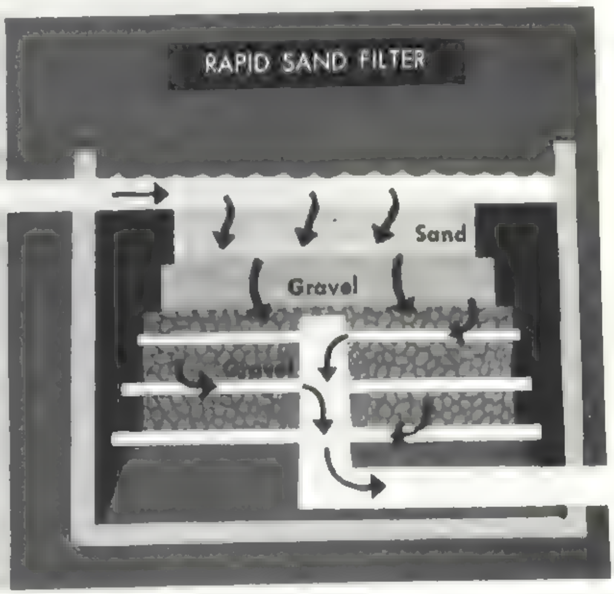
CLEANING FILTERS

The operators clean the filters by backwashing—that is, by directing a stream of water upward through the filter through the same pipes that carry off the purified water. The accumulated solid matter in the filter is discharged together with the backwash into a sewer. Backwashing must be done care-

Water flows into the tank through a riser. The sludge settles at the bottom of the tank and is pushed by rotating blades into a well, from which it is piped away.



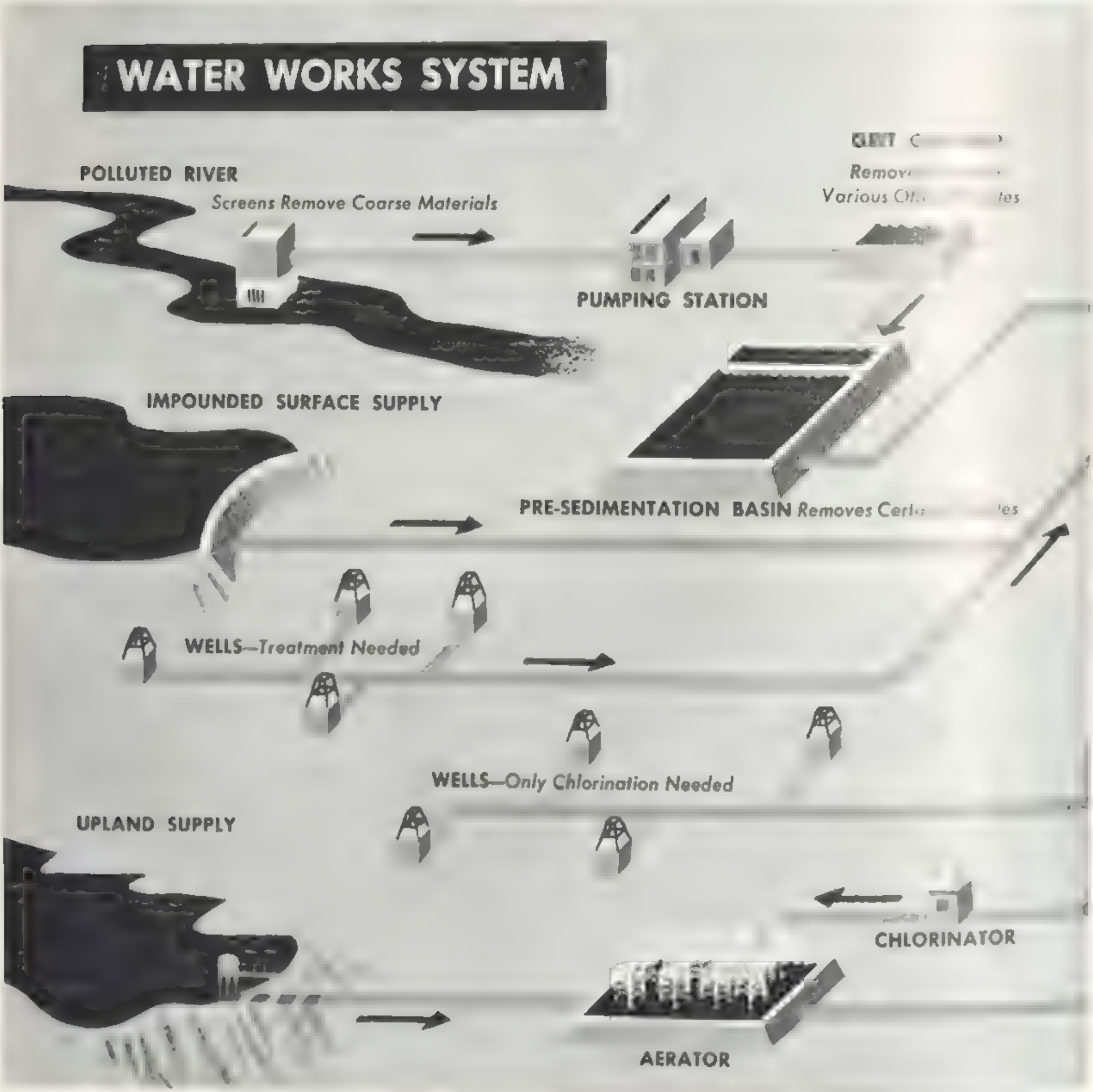
This filter finishes the purification operation. Coarse sand is set on a layer of gravel. After the water has passed through the sand and gravel, it is drained off.



fully. If it is too violent, the coarse gravel particles at the bottom of the filter will work their way to the top.

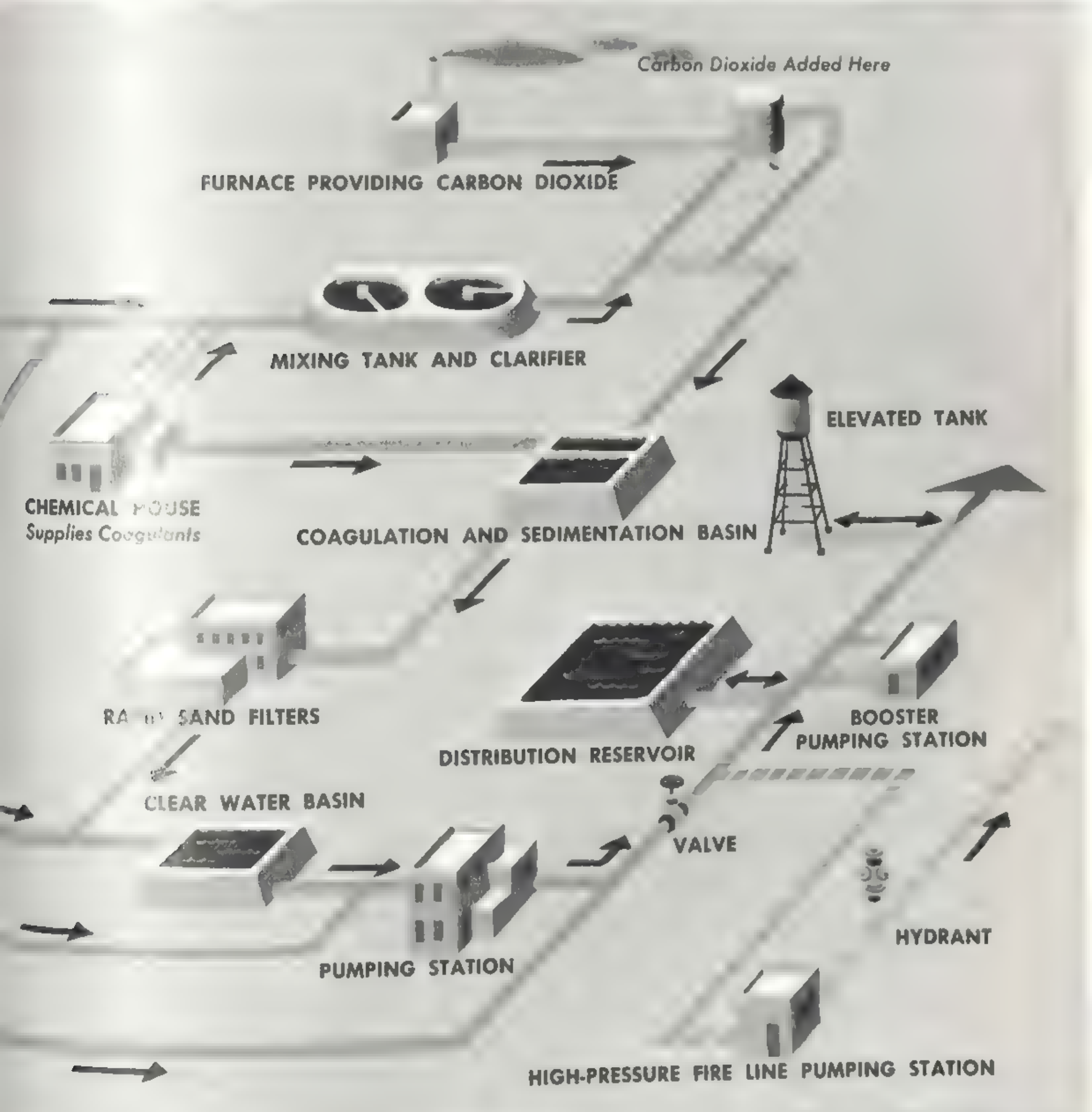
Many modern filter plants also use a surface wash to help clean the filter. Normally the surface of the filter will become dirtier than any other part. If backwashing does not remove all the sediment, accumulated mud will form into balls and w... ...se difficulty. To ensure thorough clea... ...at the surface, designers have suppli... ...ll pipes with 6-millimeter nozzles ... ...of water are directed through the no... ...to the surface area. By stirring up th... ...e thoroughly, they free it from silt

The final step in the purificatio... ...o-



cess is to see to it that there is a proper amount of chlorine, in the form of hypochlorous acid, in the water, in order to guard against contamination in the distribution system. The chlorine that was added to the water at the outset may have been used up, during coagulation and filtration, in oxidizing organic matter. If this is the case, the operator will have to add more. As a rule, he will try to have not more than one part per million of chlorine in the water as it leaves the plant. If there is too much at this stage, he reduces the content by adding sulfur dioxide.

Chlorine may have to be added to the water again and again. In such cases, it is



force of gravity. Generally, however, pumps are required to send it through the distributing system. The earlier pumps were of the piston type. A large piston would draw water into a cylinder. On its return stroke it would force this water out into the pipeline. Piston-type pumps were almost always powered by steam. They were efficient devices, which could be operated without difficulty at various pumping rates. But they were huge and costly. They were so tall that they had to be housed in large buildings. Of course steam-driven pumps required boilers. These were often inefficient, and it was costly to keep them in repair.

About 1915, waterworks scientists began to adopt the small, powerful centrifugal pump. Today it has made the old piston pump almost obsolete. A centrifugal pump consists of a wheel, called an impeller, rotating in a casing. The water enters through the center of this rotating wheel and is thrown violently to the outside. It leaves the pump under a pressure of about 3 kilograms per square centimeter. This pump is efficient, economical, simple, and quite small, requiring only a limited amount housing. It can be built to furnish almost any amount of water against pressure hea of up to about 75 meters. *Head* is a measure of the height to which water is raised by the pressure causing it to flow.

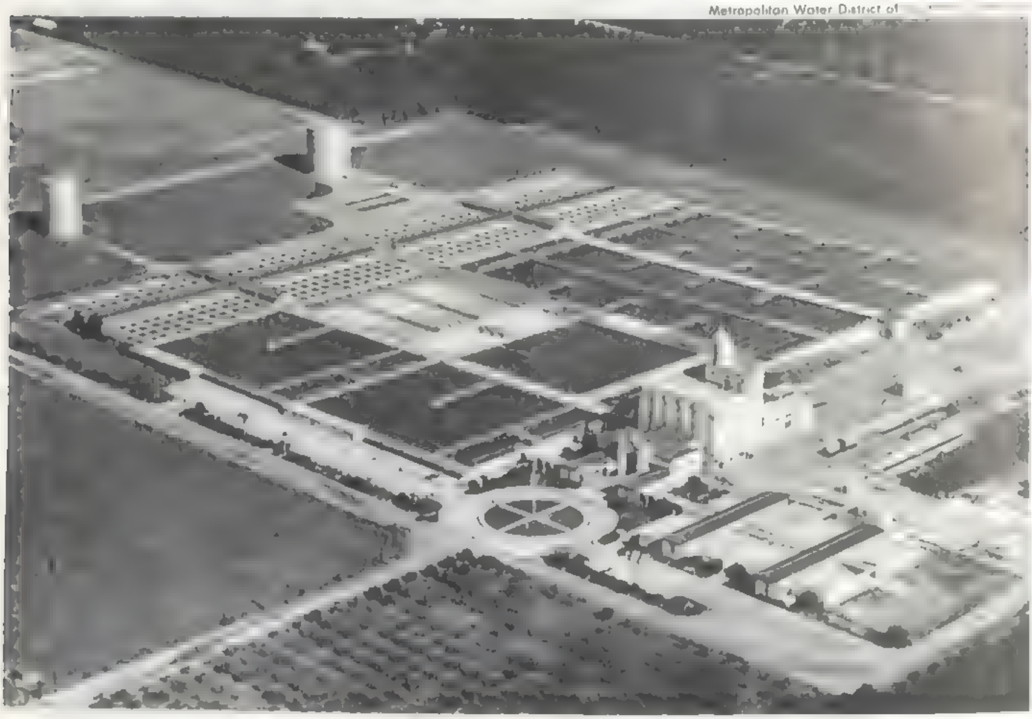
Centrifugal pumps can be driven electric motors or internal combustion gines, such as gasoline or diesel engi Large units are sometimes operated steam turbines. Such pumps are low in co simple in operation, and easily repai Their only disadvantage is that their rat flow cannot be regulated easily.

ELEVATED WATER TANKS

Reservoirs form an essential part of most water-distribution systems. Som these reservoirs serve primarily to stor

Photo showing a modern water filtration plant. Rapid sand filtration is one of the last steps in water treatment, putting the finishing touches on the purification processes

Metropolitan Water District of



water. Others are intended to equalize the rate of water flow. These consist of elevated tanks, which may be built on high ground or set on towers. Such elevated storage tanks "float" on the distribution system. This means that a tank has a single riser pipe connected with the supply main. Through this one riser pipe, water may enter the tank or may be discharged from it.

When such elevated tanks are provided, waterworks pumps operate twenty-four hours a day at a steady rate. During the night, when the demand for water is very low, the pumping rate is greater than the demand. Water is then forced upward into the storage tank. In the morning, when household activities begin, and later, when the city's industries start operating, the demand is greater than the pumping rate. Water then flows out of the storage tank, through the force of gravity, and into the distribution system.

Without overhead storage tanks of this type, a city would have to pump directly to the mains as much water as would be needed for any particular part of the day. This means that the pumps would have to be big enough to supply heavy emergency flows such as would be required for fire fighting. The pumping rate would have to vary to meet the changing demand for water throughout the day. Elevated storage tanks keep a large volume of water in reserve. This will be available under pressure to meet normal variations in water requirements or any emergencies that may arise.

Distribution systems must provide adequate water for fire protection. The figures for the number of liters per minute and the total number of hours the water is required to flow in fighting fires vary, depending on the size of the town or city in terms of population. For large urban areas, the quantities of water needed are tremendous—thousands of liters per minute for hours at a time.

The spacing of fire hydrants is also an important factor in the fighting of fire. Many cities space their hydrants so that no line of hose will exceed a length of about 150 to 180 meters. At least half the streams needed at any point should require hose lengths considerably less than the above figure.

WATER MAINS

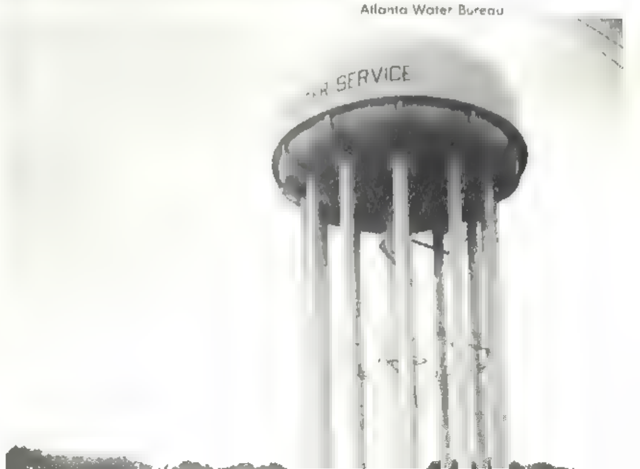
All well-designed water-distribution systems make use of a network of mains—pipes of large diameter running underground. A single water main serving a large area is undesirable. In such a pipe, called a *dead end*, the water gradually loses oxygen and becomes stale and objectionable. Furthermore, it is dangerous to rely on a single water main. If it should be put out of operation, the water supply of the entire area will be cut off.

Very often, when a city is located on a hillside, it is necessary to divide the distribution system into two or three sections. This is to prevent excessively high pressures in the lower portions of the system. There are as many as five or six of these sections in some cities.

Water mains are provided with valves, which permit the flow of water to be shut off completely in the event of a break or some other emergency. From the main, water flows through a network of pipes to the individual buildings of a community. If a building is very tall, the operating pressure may not suffice to raise water to the upper stories. In such cases, a pump in the basement of the building forces water up to a tank on the roof. From this tank, water is distributed to the upper stories. The lower stories are supplied by pipes leading from the main. The operating pressure in the main suffices to raise water to the required heights.

Elevated radial cone water tanks like this one are frequently used in water distribution systems

Atlanta Water Bureau



ENVIRONMENTAL POLLUTION

by Henry Lansford

On a road leading to Washington, D.C., a 1968 two-door green convertible breaks down. The driver gets out of the car and walks away, with no intention of returning. The car thus becomes a statistic: one of the more than 5,000,000 automobiles discarded in the United States every year. Their rusting, broken bodies mar the landscape of the entire nation.

On the French and Italian Rivieras, tourists no longer see deep-blue, sparkling waters. The Mediterranean is turning gray. Rivers and canals pour sewage, detergents, and industrial wastes into its waters; tankers flush their holds near the coast; bottles, rotting garbage, and oil slicks wash onto the beaches.

In Singapore, noise causes a variety of physical and psychological stresses. Suicides in high-rise apartment buildings are often attributed to neighbors' radios, construction machinery, and traffic noise. Even the clacking of Mah-Jongg tiles has been criticized.

In the Soviet Union a chemical manufacturing complex near Leo Tolstoy's former estate has been discharging chemical wastes into the air for ten years. As a result, oak and pine forests in this internationally known tourist area are being destroyed.

These are not isolated incidents. Rather, they are part of a worldwide pollution crisis caused by our mismanagement of the environment. We have poisoned the air, water, and soil with pollutants. We have upset natural communities in ways that are affecting our own place in the complex system that has been called "the great chain of life." And we may be tipping the balance of great natural forces in the earth, atmosphere, and oceans in ways that could be disastrous for humanity. We have reached a point at which we must begin to protect the environment in order to protect ourselves.

POLLUTION: FAD OR FACT?

Until recently, there were many w[illegible] asserted that environmentalism was a [illegible] and that man's impact on the environm[illegible] was a threat only in terms of the interests of a few bird watchers, trout fishermen, [illegible] scientists. But as the decade of the 1[illegible] opened, many people began to see seri[illegible] threats to the quality of the environment[illegible] report, by the United Nations Secreta[illegible] General's office on environmental deter[illegible]ration in the face of a rapidly increas[illegible] world population states: "The need to p[illegible]vide food, water, minerals, fuel and ot[illegible] necessities for such increasing numbe[illegible] people will place pressures on virtuall[illegible] areas of the earth and demand the [illegible] careful planning and management of natu[illegible] resources. No nation can any longer be [illegible]lated from these global pressures."

World leaders have come to recog[illegible] that an environmental crisis exists. H[illegible] serious is this crisis? Perhaps it is not [illegible] bad as some scientists believe. Perhaps i[illegible] worse. We are becoming more and more aware of the seriousness of our impacts on the environment. Each new piece of evidence emphasizes how little we understa[illegible] the extent of these impacts and the environ[illegible]mental interactions that can grow from some of them. We know, for example, that a large part of city smog comes not from the visible pollutants that belch out of industrial smokestacks, but from chemical reactions produced by the action of sunlight on invisible gases that enter the air in automobile exhaust fumes. We are now discovering that this smog can kill, and is killing, valuable timber. Large-scale destruction of plant life in turn presents a serious threat to all animal life.

Scientists have begun to identify some of the causes of pollution on a local scale.

Editorial Photocolor Archives, Inc

Mark Lane

Pollution now affects the earth's atmosphere, water, and landmasses. Above: an all-too-typical view of twilight over a city. Left: an auto graveyard, just one of the blights now common in rural and urban land areas.

Much less is known about global environmental problems. Guesses are not good enough. We cannot afford to gamble on the proposition that we are creating global environmental catastrophes. We should decide which of our activities need closer examination. Then scientists should evaluate exactly what these activities are doing to the environment and how they are doing it. Finally, their findings should be readily available to decision makers in governmental and other institutions who can guide public policy in directions that will avoid environmental catastrophes.

AN ECOLOGICAL VIEW

Pollution may be defined simply as the accumulation of something where it is not wanted. This is a human-centered definition, based on human preferences and de-

EPA

This trickle of sewage into a stream illustrates just a part of the problem of water pollution—now a serious problem in many parts of the world.

sires. The simplest human reason for not wanting a particular pollutant in a particular place is that it has a directly harmful effect on people: it threatens their health or assaults their senses. Thus we speak of the visual pollution of neon signs or the noise pollution of jackhammers.

But a broader and more subtle definition of pollution concerns its effect on systems where people are only one of many elements. This definition involves an ecological view of pollution, and it requires a readjustment of some traditional concepts of our place in the world.

Ecology is the branch of science that is concerned with the relationships of life forms with each other and with their surroundings. The basic unit in ecology is the *ecosystem:* a fairly self-contained system of plants and animals living in a particular kind of environment. A forest is an ecosystem; so is a lake. Every ecosystem has four elements:

(1) The nonliving environment. This includes sunlight, water, oxygen, minerals, and dead plant and animal matter.

(2) Producers. These are green plan which range in size from the microscop phytoplankton to giant redwood tre They have the unique ability to absorb t sun's energy and use it to produce foods

(3) Consumers. These are anim both herbivores, which feed on plants, carnivores, which eat other animals.

(4) Decomposers. These include b teria, fungi, and insects that break d dead plants and animals. In the pro they release energy into the environ and return matter to the soil. The m provides nourishment that is absorbe green plants and started through the again.

In theory the ecosystem is a cl cycle. But in practice ecosystems are dom in a state of balance. Natural chan which gradually shift the composition o ecosystem, occur continuously. An eco tem that supports many kinds of g plants and animals is not likely to b rupted by such changes. If one speci lost, many others remain to continu cycling of materials and energy. O other hand, an ecosystem with only a species may collapse if the environ changes suddenly, killing one or two cies. Throughout the *biosphere*—that of the world where life can exist—the s principle applies: wherever diversity lacking, ecosystems tend to be unstable fragile.

MAN IN THE ECOSYSTEM

Like all other living things, we are element in various ecosystems. Tod however, we sometimes dominate ecos tems to such an extent that the role of other elements is not clearly visible. In earlier days our place in ecosystems was not so disproportionate. Peoples who lived by hunting, gathering, and simple horticulture were in harmony with all elements of their ecosystems, filling a *niche,* or specific place, in the ecosystem but not dominating it.

The use of the plow and draft animals was the beginning of the agricultural ecosystem dominated by man. Subsistence farming is a fairly simple ecosystem, but its

character clearly is dictated by the needs of man. The farmer planted crops and raised animals to supply the needs of his family. Grain was the producer that converted the sun's energy and nutrients in the soil into food. The livestock ate the grain, and the farm family ate the meat and drank the milk: they were the consumers. Animal manure was spread on the fields and decomposed, returning nourishment to the soil for next year's crop.

A simple ecosystem by modern standards, subsistence agriculture is highly artificial and specialized compared with the grasslands or forests that it displaces. The agricultural ecosystem lacks diversity and is thus very fragile. Without constant attention from man the fields soon begin to revert to grassland or forest. Or, if the climate fluctuates, the result can be ecological chaos.

In our complex industrial society, we have created ecosystems, such as cities, that are very specialized and consequently very fragile. We have kept them going by brute force, through massive applications of technology. Have we made many cities unbearably hot in summer by paving hundreds of square kilometers of the earth's surface? No matter, we'll install more air conditioners. This sort of "technological fix" has made cities the focal points of some ecological blunders. Urban pollution problems should be recognized as precursers of problems that sooner or later will occur on regional, national, and global scales.

WHAT IS A POLLUTANT?

Pollution, we said, is the accumulation of something where it is not wanted. Pollutants may be unwanted for a variety of reasons. They might, for example, be desirable if they were somewhere else. Crude oil is valuable when it is piped into refineries to supply fuel for cars and power plants. But adrift on the ocean, headed for the beaches of England or the oyster beds of Louisiana, it is a pollutant. DDT has saved many lives by killing mosquitoes that carry malaria and other diseases. But when DDT accumu-

Industrial waste also pollutes waterways. Here a large industrial waste outlet pours out waste from lumber mills, metallurgical plants, and canneries. In many countries there are now government controls to prevent this type of pollution.

Fish Commission of Oregon

lates in the bodies of fish, birds, and other wildlife, it is a pollutant. Heat is useful, but when it is discharged in large quantities into cold, clear streams or lakes, it causes *thermal pollution*.

Other pollutants are always undesirable. Radioactive fallout, for example, has no redeeming features regardless of where it is. Chemical and biological weapons present a dilemma when they must be discarded. They are pollutants wherever they are dumped. Certain items become undesirable after they have served their purpose. Aluminum cans are useful containers, but nobody wants them once they are empty.

Other substances become pollutants when they accumulate in large concentrations. The hiker who backpacks into the wilderness does not find flush toilets at his campsites. His sanitary arrangements consist of a small hole dug in the ground and covered up after he has used it. Decomposers in the ecosystem break down the wastes. But sewage disposal for a city of one or two million people is another matter. If proper treatment plants are not availab water pollution is the inevitable result.

GROWTH OF POPULATION AND TECHNOLOGY

Two basic factors have made pollu an ecological problem: population gr and the spread of technology. There many more people on our planet than before, and many of them are or will be using technology on an unpreceden scale. This combination of exploding p ulation and galloping technology mea are using tremendous amounts of en and raw materials from the earth. It that we are creating great amounts of causing a worldwide ecological crisis.

In the next few pages we will exa several important examples of environ tal pollution. These examples either re sent serious potential threats to env mental quality, or they illustrate the lems and complexities of anticipati avoiding undesirable human impacts environment.

With increasing water pollution, large fish-kills, like this one, have become commonplace. In one year an estimated 23 million fish in United States waters died from the effects of pollution.

WATER POLLUTION

M[illegible] times each day we turn a handle to pro[illegible] a flow of clean water. By pressing an[illegible]r handle we flush away our body wast[illegible]t how often do we consider the comp[illegible]stems that provide our water and d[illegible]e of our sewage?

[illegible] water supply usually comes from [illegible]nt location, but its sewage enters [illegible] waterways. If the decomposers in th[illegible]ic ecosystem cannot cope with the [illegible] of sewage, the beaches and wat[illegible]nes of areas farther downstream bec[illegible]luted

[illegible] real concern with water pollution [illegible]n the late nineteenth century. The [illegible]al revolution had spurred the grow[illegible]ities, and the common practice of d[illegible]sewage into the nearest stream had [illegible] many rivers into cesspools. Mu[illegible] cities' drinking water was drawn from the same rivers, resulting in great epidemics of cholera, typhoid, and other diseases. London's history provides a classic example. Sewage had turned the Thames into a mass of filth, and 20,000 Londoners died in cholera outbreaks in 1849 and 1853. During the same period, typhoid epidemics hit many cities in the United States. Circumstantial evidence indicated that these diseases were transmitted through polluted drinking water. But there was no real understanding of how this happens until the 1880s, when scientists made major discoveries about the role of bacteria in many diseases. This new knowledge marked the beginning of sewage-disposal technology.

London built large sewers that ran parallel to the Thames, diverting the sewage into the river far downstream from the city. This pioneering sewage-disposal project foreshadowed the principle that would pre-

This [illegible]een the "dump" not only for liquid wastes from factory operations [illegible]olid waste. The level of toxic metals in many bodies of water has [illegible]ng. If such toxic substances find their way into drinking water sup[illegible] and severe – diseases could result

EPA

Even the oceans have become polluted. Oil ... present a serious danger as the demand for ... transport of oil increases. Above: wreck of a ... that left a 35-centimeter thick spill along San ... Puerto Rico harbor and blackened much ... nearby shoreline. Left: an oil-containment b... being tested in the Gulf of Mexico

vail for years: get the stuff away from our city and don't worry about downstream.

Emphasis on public health and unconcern with anything but local contamination characterized the public's approach to water pollution until the late 1960s. Industrial pollution was virtually ignored. It was taken for granted that rivers and lakes were logical places to dump anything that needed to be dumped. State game commissions occasionally fined factories that killed large numbers of fish, but the general decline in water quality was tacitly accepted.

Now, however, people have become concerned about the condition of surface waters. This concern has grown partly ... of an increasing interest in outdoor life ... an appreciation of clear streams and la... But most of the concern stems from the ... that clean water is essential for drink... industry, agriculture, and recreation.

Yet in nearly every part of the w... water pollution has reached a danger... level. In Holland, for example, the R... River is called the "sewer of Europe ... the time the river reaches the Dutch c... it is 20 per cent sewage and indus... waste. The Iset River in the Soviet Un... loaded with volatile industrial wa... caught fire when a cigarette was flip... into it. In an almost identical incident, ... Cuyahoga River in Ohio also caught ... and burned up two railroad trestles bef... it was extinguished.

SEWAGE CRISIS

Incidents like these could become more and more frequent as population growth and the spread of urban areas intensify the problems of waste disposal. In areas where the suburbs of one city merge with those of the next one – such as the U.S. megalopolis called "Bosnywash," for Boston, New York, and Washington, D.C. – sewage alone has placed a tremendous burden on comparatively few rivers, bays, and estuaries.

Lakes and rivers, like all ecosystems,

have built-in waste-disposal mechanisms that work very efficiently as long as they are not overloaded. The decomposers in an aquatic ecosystem can usually handle a considerable load of human organic waste in addition to the dead plant and animal matter that originates with the ecosystem. Ecologically, there is nothing wrong with dumping raw sewage from a small town into a large river.

There are aesthetic and sanitary objections, of course, but the decomposers in the river ecosystem will go to work on the sewage, and a few kilometers downstream the river will have cleansed itself. Microorganisms in the water break down the organic wastes and release their inorganic ingredients. These ingredients nourish the producers of the river ecosystem: tiny plants known as algae.

TOO RICH WATERS

The process of enriching waters with nutrients is called *eutrophication*. This is a natural process that occurs in any river or lake. A young lake, for example, is relatively clear, and its water is low in nutrients. Over a period of thousands of years, nutrients collect and the lake becomes rich in plant and animal life. But eventually there is an overabundance of nutrients. Plants become the dominant life-form. As the plants die and decay, the oxygen in the water is used up. Without oxygen the fish die, thus adding to the accumulation of decaying matter. Slowly the lake turns into a swamp.

Man can speed up this process by dumping too much sewage into the water. When a town grows into a city, or when many towns and cities are built along the same river, the ecosystem is overwhelmed by the large amount of wastes. Thus sewage treatment becomes necessary.

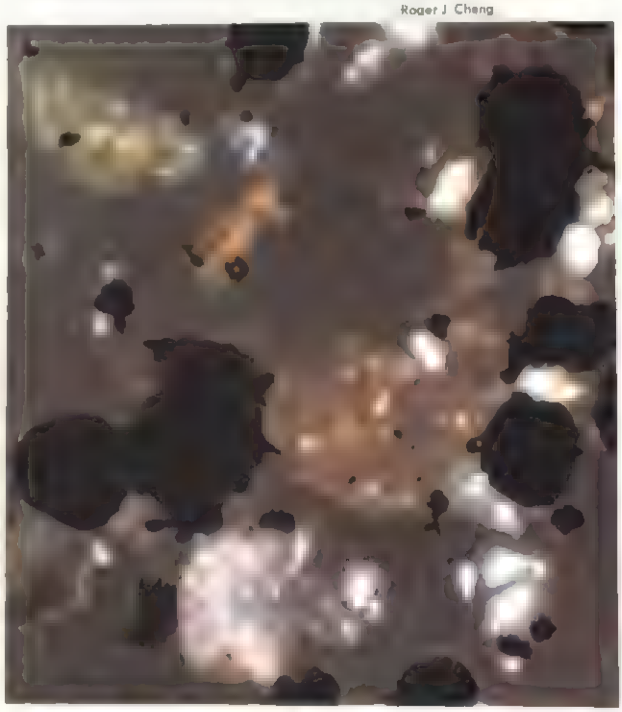
Modern sewage technology shows an understanding and application of part of the aquatic ecosystem. Sewage-treatment plants, for example, utilize the same microorganisms that serve as decomposers in natural bodies of water. But as urban growth and population have continued to increase, it has become apparent that sewage-treatment technology is only partly in tune with the ecosystem. It avoids overloading the decomposers directly. However, the nitrates, phosphates, and other nutrients released from the organic matter by the microorganisms in the sewage-treatment plant are passed on through the ecosystem, where they stimulate the growth of algae. Thus the end result is eutrophication.

Algal overgrowth has been a major factor, for example, in the breakdown of the ecosystem in North America's Lake Erie. The combination of ecological disruption and poisoning by industrial wastes has been more than the ecosystem can absorb. It will be difficult or impossible to restore the lake to its former state. It is interesting to note, however, that the lake is very productive biologically.

Sewage is not the only source of excess nutrients in surface waters. Chemical fertilizers are often washed out of the soil by rain. They eventually drain into streams

Dust tells a lot about the environment. This microscopic view shows the diversity of particles found in one air-pollution experiment done in a large city

Roger J. Cheng



Inspectors clothed in protective garments check stored industrial wastes for harmful chemicals

and rivers, where they nourish the algae as effectively as they would have nourished the farmer's crops.

Fertilizer drainage is causing deterioration of the Sea of Galilee, also known as Lake Kinneret. The lake, which is fed by the Jordan River, furnishes one-third of Israel's water supply. Nitrates from an agricultural area along the Jordan have been flowing into the lake and destroying its powers of self purification.

Another major source of excess nutrients is detergent phosphates. Phosphates add cleaning power to detergents, but as they pass through the sewage system they break down to phosphorus, an important factor in eutrophication. From 50 to 70 percent of the phosphorus flowing into rivers and lakes in the United States each year comes from the breakdown of detergent phosphates. Europe is also beset with the problem. Lake Constance, on the border of Germany, Austria, and Switzerland, has had, for example, a 2,500 percent increase in phosphorus content since 1920, and about two-thirds of its oxygen is depleted. However, it has not been proved that limit detergent phosphates—as some communities have done—will solve the probl Phosphorus comes from other sources other elements—carbon and nitrogen example—are also controlling factors in trophication.

INDUSTRIAL POLLUTANTS

Industrial plants are an even gr menace to aquatic ecosystems. Fac discharge three or four times more ox demanding waste than sewers do, and dump poisons into the water as well nology can remedy some of the imp these industrial wastes. But some may simply have to be eliminated. The erage waste from the modern sulfate and paper process is less than one-ten what it was from the sulfite proce merly used in paper mills. In this case technology has effected a great imp ment. But new and complex chemic cesses used in industry have increa possibility of releasing dangerous ch pollutants that are hard to control.

The mercury problem is one ex of pollution caused by industry. Me waste product of a variety of indu moves along the food chain from wat plants to fish, birds, and humans. M poisoning in humans causes head dizziness, and fatigue in mild case severe cases there is kidney damage vous system disorders, and possibly de

The mercury problem was notice 1969 when a Canadian study showed levels of mercury in Lake St. Clair Since then, potentially dangerous leve mercury have been found in some bodi water in the United States and in the Gr Lakes region of Canada. Bans on sport a commercial fishing in affected waters a common in both countries.

The discovery of high levels of mercury in random samples of canned tuna and frozen swordfish sold in the United States led to a recall of these products and a ban on the sale of swordfish. However, in this case, further study revealed that the recall was not necessary and that the mercury content was not unusually high.

The poisonous effects of mercury were demonstrated in Japan between 1953 and [illegible]. A plastics manufacturing plant had been emptying mercury into Minamata Bay on the Japanese coast. The mercury became concentrated in the tissues of fish. Over 100 people who had eaten fish from the bay either died or became disabled from the mercury.

Cadmium and arsenic are two more toxic metals that have been building up in water supplies. Cadmium causes liver damage and high blood pressure in humans. The toxic effects of arsenic on humans are not known yet. Since the tissues build up a tolerance to arsenic, death is prevented except from an excessive dose. But arsenic is a serious threat to fish populations.

Scientists require a great deal more knowledge about the effects of low-level, long-term exposure to the toxic metals. However, a number of scientists believe that unless preventive measures are taken now, diseases caused by metal poisoning could emerge in the near future.

[illegible] is another industrial water pollutant. Electric generating plants, nuclear power plants, and many manufacturing operations require enormous amounts of water for cooling. This water is usually drawn from lakes or rivers. The hot water is discharged back into the same lake or river. If this water is hot enough to raise the average temperature in a large volume of the stream or lake, it can radically upset the ecosystem. Plants and animals adapted to a certain temperature range may be unable to survive when the temperature rises a degree or two above the upper limit of that range. If one or two species disappear, the ecosystem may not have sufficient diversity to compensate for the loss, and it may break down completely in time.

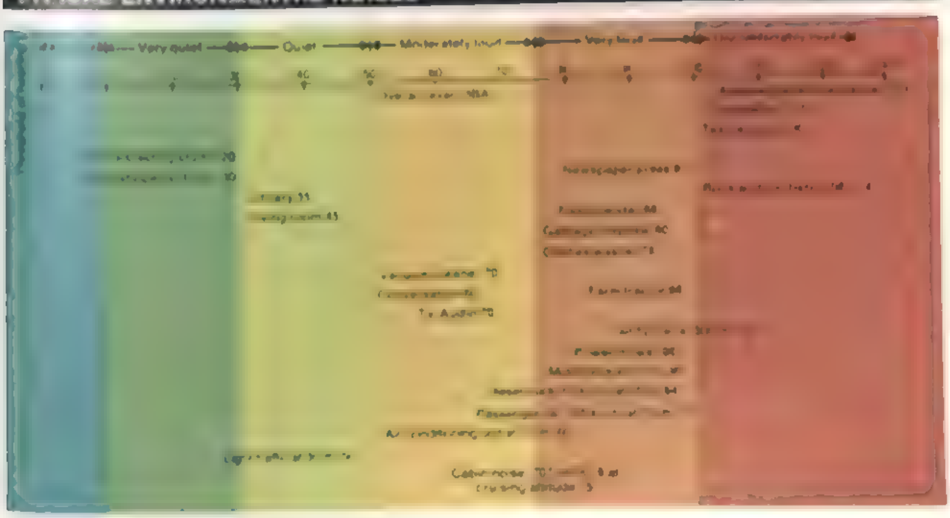
Recently two industrial chemicals have received wide publicity for finding their ways into water sources: polychlorinated biphenyls (or PCBs) and dioxins.

PCBs are pervasive in the environment even today. In the past they were primarily used in electrical transformers and capacitors, in printing and copy papers, and as additives in certain industrial fluids. Their production was banned in 1979, but the chemicals still linger in the environment. Also, we still have about 750 million pounds of PCBs either in storage or in use.

According to a national health study, almost all Americans have detectable amounts of PCBs in their fat tissue. Several studies also indicate that, at high levels, PCBs are toxic and cause cancer in animals. In fact, some experts claim that PCBs rank third in toxicity behind dioxins and furans.

Noise is a stress and has significant physical and psychological effects on people of all ages. The chart shows typical environmental noises. Noise is measured in decibels, with one decibel the least the human ear can detect. Noises above 85 to 90 decibels are considered dangerous.

TYPICAL ENVIRONMENTAL NOISES



Dioxins, too, show up in the environment from several sources. For one, dioxins are an unwanted by-product of herbicide and disinfectant production. Dioxins often show up as serious health and environmental threats when they are improperly disposed of or when traces remain in herbicides and disinfectants. Dioxins are also of particular interest because they were contaminants in some batches of Agent Orange, a defoliant used during the Vietnam War.

Dioxins are highly toxic. For example, an oral dose of 0.8 micrograms of dioxin can kill a hamster; dioxins are toxic to the mosquito minnow at three parts per trillion. Two well-documented effects in humans are skin eruptions—called chloracne—and a high risk of developing soft-tissue malignancies. According to some scientists, even the slightest trace of some dioxins in the environment may have adverse effects on the health of both humans and animals.

Since 1977, many Vietnam veterans have blamed a wide range of medical disorders, including cancers and birth defects in their offspring, on dioxins. Studies are currently under way to determine if dioxins in Agent Orange are responsible.

More recently, extensive dioxin contamination was discovered in Times Beach, Missouri. The dioxins were traced to an oil sprayed on roads in Missouri; the oil was accidentally contaminated with dioxins. The dioxin contamination spread from its original site to pollute other soils and waterways.

Dioxin contamination is persistent. New scientific data indicate that the half-life for dioxin breakdown in the environment may be as long as ten years. The danger from the dioxin contamination will not disappear quickly. It may be necessary to treat, excavate, and move the contaminated soil to special landfills.

Acid rain, another indirect form of industrial pollution, results from the interaction of the atmosphere with industrial pollutants (oxides of sulfur and nitrogen formed in combustion of fossil fuels, mainly by power plants). These pollutants change chemically and become acid aerosols that drift in the atmosphere for weeks, then combine with water, and precipitate as dilute acid in snow and rain.

Acid rain is responsible for a variety of problems. It makes some lakes so acidic that most or all fish species are unable to survive. Acid rain causes toxic metals to enter water supplies because the acidic water leaches them from soil. On land, acid rain can retard the growth of crops and plants and poses a potential respiratory health hazard to humans. (See the article on Acid Rain.)

EVEN IN THE OCEANS

Pollution of the oceans, like global air pollution, is not very well understood at this point. However, many of the pollution problems that affect rivers and lakes also affect the estuaries and coastal zones where the continents meet the oceans.

Thor Heyerdahl, during his expedition on the *Ra II,* found pollution in the middle of the Atlantic. He and his crew sighted "brownish to pitch-black lumps of tarlike or asphaltlike material of the size of fine gravel in widely separated parts of the ocean." Heyerdahl also found that "the ocean water assumed a very dirty, grayish green color instead of clear blue, leaving us with the impression of being inside a harbor amidst the outlet of city sewers."

Large-scale disturbances of marine ecosystems could produce complex and far-reaching effects. It is critically important for man to learn much more than he knows now about the physical and biological processes of the oceans.

Oil spills are a good case in point. Although crude oil has spilled into the ocean from wrecked tankers or offshore oil wells many times in the past, some oil spills have provoked a great deal of public attention and controversy. The Santa Barbara, California, spill in 1969 became the focal point for many arguments over what damage resulted from the blowout of a well in the Santa Barbara Channel. The damage to the beauty of the beaches was obvious. It was equally clear that some birds and other creatures were killed by the oil. But nobody could say with certainty what long-term

ecological consequences might result. Just after the spill occurred, there were claims that the Santa Barbara Channel had become an "ecological desert." Recent investigations seem to indicate that the damage was not that serious.

However, oil is the main pollutant in the Mediterranean, which is on the way to become a dead sea. An international conference in 1971 on the island of Malta selected the Mediterranean as a prototype of a polluted sea. Scientists and diplomats from the countries agreed on the need for multilateral pollution-control legislation to save the Mediterranean. The consensus was that oil is the most serious pollutant and that new legislation should be formulated to control oil tankers, refineries, terminal pipelines, and the discharge of tank washings from oil carriers.

Editorial Photocolor Archives

Community members gather to help cleanup after a severe oil spill along a beach.

AIR POLLUTION

Our air, like our water, is being poisoned with the by-products of an expanding technological society. Air pollution is not a new problem. As long as man has lived in cities he has polluted their air. What is new, however, is the scope and severity of air pollution. Most of the world's major cities must now strive to deal with high levels of air pollution. In addition, smog from cities is drifting into many suburban and rural areas where it is fed by cars, incinerators, and heating plants.

Urban air pollution was once considered to be solely a problem of smoke in the air. The main source of the smoke obviously was industry, which burned great quantities of coal, oil, and other fossil fuels. The word *smog* was coined and was generally assumed to denote simply a mixture of smoke and fog.

However, the fact that Los Angeles, California, which did not have heavy industrial complexes and burned very little coal or oil, was one of the world's most smog-ridden cities in the 1950s and 1960s indicated that smog was a more complex problem.

There is a chemical explanation for the smog problem. Certain compounds that are present in automobile-exhaust emissions—gaseous hydrocarbons and oxides of nitrogen—are invisible as they enter the atmosphere. Once in the air, however, they react under the influence of sunlight to form the ingredients of *photochemical smog*, a noxious form of pollution that brings tears to our eyes and makes us cough and choke as we breathe it. The combination of large numbers of automobiles and local weather conditions made Los Angeles particularly subject to photochemical smog.

But automobiles are a major source of urban air pollution everywhere. For example, photochemical smog has put Mexico City on the list of the world's most polluted cities. Automobiles, buses, and trucks account for 60 per cent of the air pollution, with carbon-monoxide levels in Mexico City exceeding those in Los Angeles. Similarly, Sydney, Australia, long believed to be the last outpost of the clean environment, is plagued with a higher percentage of automobile emissions in the air than that of any city in the United States.

Like bodies of water, the atmosphere can cleanse itself of pollutants as long as they are not produced in large quantities


EPA


Arthur Witman, [illegible] ouis Post Dispatch

Top: Cleopatra's Needle, an ancient Egyptian obelisk in New York City. Its hieroglyphic inscriptions, 3,500 years old, have been corroded by the city's polluted air—caused in part by belching smokestacks (lower) and other industrial pollution

and concentrations. Cities accumulate pol lutants both because they produce them i such large amounts and because cities a often located in river valleys, along bays on level areas beside mountains. Such ar are often subject to *temperature inversion* This is an atmospheric condition in which layer of warm air lies above a layer of air. The cold air is heavier; thus it rem near the ground, and pollutants accumul in it.

In a normal situation, air nea ground is warmed by heat radiated fron ground. The air rises, carrying the po tants upward to be dissipated by wind the upper air. When an inversion is pres the warm air that lies above the cold a like a ceiling. It traps the pollutants, wl can accumulate to dangerous concen tions if the inversion remains for a l enough time. Denver, Colorado, a city noted for its clear air, has reached emer cy levels of air pollution several times w temperature inversions existed. At times only the onset of strong mou winds, which broke up the inversio allowed the pollution-laden air to away, saved the city from declaring a pollution emergency.

EFFECTS

Air pollution has wide-ranging fects—on people, on other life forms, and even on inert materials. In October 1948 a stagnant fog, heavy with pollutant blanketed the small industrial town Donora, Pennsylvania. The fog lasted for four days. By the time it had been cleared 6,000 of the town's 14,000 people were sick and 20 had died. Four years later, a "killer smog" in London caused an estimated 4,000 deaths. In 1970 more than 8,000 people in Tokyo needed medical treatment for eye, nose, and throat irritations when a heavy white smog, containing sulfurous acid, covered the city for five days.

The most serious and immediate menace of air pollution lies in its physical effects on human beings. It is difficult to assess the long-term health effects of air pollution. But there is no doubt that ailments such as emphysema, chronic bronchitis,

bronchial asthma, and other respiratory diseases are caused or aggravated by regular exposure to present levels of city air pollution.

Air pollutants abrade, corrode, tarnish, soil, erode, crack, weaken, and discolor materials of many varieties. For example, steel corrodes from two to four times faster in sulfur-laden air.

Air pollutants also kill and injure plants. In Tokyo, trees and shrubs are dying in the gardens of the Imperial Palace. In northern Bohemia, Czechoslovakia, polluted air from the brown-coal belt has caused blight in agricultural areas and has heavily damaged forests.

DISRUPTING CLIMATE

We now have an understanding of how air becomes polluted on a local level, and we have some idea of how to remedy the problem. But global air pollution is not so well understood. Data are fragmentary, and knowledge of large-scale effects of air pollution is sketchy. We do not know what man is putting into the atmosphere on a global scale. Nor do we know what processes the pollutants become involved in once they are in the air. Thus we cannot determine the ultimate effects of this pollution.

The data that do exist are not encouraging. Scientists of the U.S. National Oceanic and Atmospheric Administration (NOAA) report that the atmosphere over the North Atlantic is getting progressively dirtier.

What will happen if this trend continues? Particles in the air decrease the amount of radiation that reaches the earth from the sun. It is theoretically possible that large amounts of particulate pollution could lower the average surface temperature of the earth to the point where much plant and animal life could no longer exist. Such a drop in temperature could also mark the advent of another ice age.

Other air pollutants have very different effects on climate. Between 1880 and the mid-twentieth century, the earth became slightly warmer. One explanation for this increase is based on the *greenhouse effect*. Like the glass roof of a greenhouse, carbon dioxide in the atmosphere is transparent to short-wave radiant energy from the sun, but tends to block the long-wave heat energy radiated outward from the earth. Thus an increase in atmospheric carbon dioxide should hold more heat in the atmosphere, raising the earth's average temperature. Carbon dioxide is produced when coal, oil, and other fossil fuels are burned. The earth's warming trend occurred during a time when industrial growth greatly increased the carbon dioxide in the atmosphere.

But about 1940 the trend reversed. Very gradually the temperature began decreasing. This change supported the theory that man-made particulate pollution was screening off more of the sun's energy. Such theories are interesting. But atmospheric scientists are still a long way from being able to predict the effect of pollution on climate.

SOLID WASTE PROBLEM

A major source of air, water, and land pollution is the massive amount of solid wastes disposed of each day by our consumer society. The United States, the world's largest consumer nation, has the most serious solid-waste problem. Household refuse, commercial rubbish, industrial

The insecticide DDT is known to affect the calcium-producing mechanism in birds. Birds so affected frequently lay eggs with such thin flaky shells that the embryo birds cannot survive.

Marine Audubon Society, Howard Mendall

Pad and Petal Garden Club, Hunter, North Dakota

Pad and Petal Garden Club, Hunter, N

One way of fighting environmental pollution is by beautifying and rec land. In Hunter, North Dakota, a civic-minded club took land that had bee as a dump and turned it into a new city park and recreational area

wastes, and construction debris total more than 700,000 metric tons daily in the United States. Among the major methods of solid-waste disposal are open dumps, sanitary landfill, incineration, ocean dumping, feeding garbage to swine, and composting. Seepage of rainwater through the wastes in dumps and landfill may result in pollution of ground water. Incineration pollutes the air. Ocean dumping may damage ecosystems in parts of the sea.

In addition, we are running out of places to put these wastes. Some cities are forced to ship their refuse long distances to suitable disposal sites. San Francisco, California, for example, has a disposal area in a desert about 600 kilometers from the city. Swamps and abandoned strip mines are also being considered as potential landfill areas.

Several solutions to the disposal problem have been proposed. One of these is *recycling*. This is the utilization of wastes as raw materials in the manufacturing of new products. Wallboard, organic fertilizers, and cellulose plastics are some end products of recycling. Putting old items to new uses is another aspect of recycling.

Another answer lies in the development of new technologies to handle the increasing mass of trash. One such syst already in use in many large apartn houses, is the garbage "compactor." compresses garbage into slugs about fourth of its original volume. On the tive side, however, this system make composition of the garbage more dif Another volume-reducing system is *ysis*, a plant operation that burns gar in an oxygen-free environment.

LAND MISUSE

Many current environmental proble have been caused or aggravated by the care less use of land and natural resourc Overgrazing of ranchland has led to er sion. Draining and dredging wetlands has led to the disappearance of coastal wildlife Dams prevent rivers from carrying sedi ment to the ocean. As a result, beaches are disappearing.

In the United States, strip mining of coal is less expensive, faster, and more efficient than underground mining. But it has transformed large tracts of land in Pennsylvania, Ohio, Virginia, Kentucky, and other states into a maze of deep pits and huge soil mounds. Once the land has been altered and exposed by strip miners, it is ugly, and vulnerable to erosion and flood-

Oregon State Highway Department

Polluted waters can be rescued. The Willamette River in Oregon was polluted by municipal and industrial wastes a few years ago, but today it is clean, because of good environmental programs.

ing. Moreover, although strip mines can be filled in and reclaimed, the process takes thirty to forty years.

Increased construction is a problem along the coasts of many nations. A report from the Council of Europe states that trampling on the coastal dunes have resulted in a loss of stabilizing vegetation and erosion of the dunes. To cope with the problem, European authorities will create stricter zoning laws in coastal areas and will attempt to build new dunes.

Construction is also causing the Black Sea coast in the Soviet Union to disappear. Building projects are so numerous that the soil is loosened and erosion speeds up. Contractors increase the damage by taking gravel from the coastal areas, while dams and reservoirs have disrupted the natural pebble-making process.

In the French Alps the massive development of ski resorts threatens to turn a region of rustic Alpine farming villages into a conglomerate of urban-style luxury resorts. The destruction of natural beauty will be coupled with an increasing danger of avalanches. Cutting trees to open up ski slopes makes a clear path for sliding snow. Also, as resorts replace farms, the grazing livestock that keep the grass short disappear. Short grass helps to keep the snow in place while long grass bends and lets the snow slide.

Urbanization has rarely been accompanied by large-scale, long-range planning. As a consequence, haphazard construction has turned many urban and suburban areas into commercial jungles. The physical deterioration of inner cities, the lack of parkland, and the proliferation of highways and neon signs all contribute to an unpleasant and psychologically upsetting environment.

WILDLIFE THREATENED

A serious consequence of land misuse is the loss of various life-forms. Urban sprawl, the spread of agriculture, the building of dams, and the loss of forests have destroyed wildlife habitats. Lands reserved for parks and refuges are dwindling. As a result, wildlife is threatened.

According to the International Union for Conservation of Nature and Natural Resources, some 550 species or subspecies of animals are currently threatened with extinction. These include representatives from every continent and ocean: the vicuña, whooping crane, orangutan, tiger, giant panda, polar bear, Tasmanian wolf, blue whale, and so on. Some 20,000 species of plants are also threatened.

Besides destroying wildlife habitats, we are poisoning animals and their food with pesticides, herbicides, and other chemicals. These chemicals have killed large numbers of fish, birds, and beneficial insects. They also threaten human life, killing hundreds of people each year and injuring thousands. They may also have harmful—as yet unknown—long-term effects.

The concentration of certain chemical pollutants is increased as they move along the food chain. A small insect nibbles at a blade of grass. A larger insect eats the small one, and is eaten in turn by a sparrow. A hawk eats the sparrow. This is the *food chain.* The little bug will absorb a small amount of a chemical if it is present in the blade of grass. The large insect, who eats a lot of small insects, will absorb more of it. And so on, with the creatures at the end of

Recycling—the use of wastes as raw material to make new products—is one answer to the problem of solid-waste disposal. Here children sort cans in a recycling collection center.

Alcoa

the chain often ending up with high concentrations of the substance.

The insecticide DDT moves along the food chain in this manner. Since 1946, DDT has been widely used as an effective weapon against agricultural pests. DDT does not break down easily in nature. Once it is in the environment it remains there for many years, concentrated mainly in birds and other animals at the end of the food chain.

DDT can cause physiological changes in animals and humans. For example, it disrupts the calcium-producing mechanism i birds. This means that their eggs are la with an inadequate, thin, flaky shell. Ma of these poorly protected embryos ne reach maturity. As a result, populations the American eagle, the osprey, the pe grine falcon, the brown pelican, and t Bermuda petrel are declining.

Too much DDT may also be reach humans—as analysis of the milk of so nursing mothers has shown. Animal search indicates that the effects of intens DDT exposure may include genetic da age, stomach and liver dysfunction, mem loss, and slow reaction time.

Governments of a number of c tries, including the United States, Cana and Sweden, have restricted the use DDT. In addition, the values of defolia and other pesticide substances are bei restudied.

AND NOW?

In this article, we have discussed the destructive impact of man on the environment. Obviously, man wants to survive, and to do that he must have breathable air and drinkable water. But how does he want to live? He may want to have blue skies and clear streams and unspoiled wilderness areas, but he can survive without them. The first step is to decide what kinds of environmental quality man wants, and how much he is willing to give up for them.

We must gain the scientific knowledge needed to understand the relationships between man and the environment. We must then apply this knowledge to protect the environment and thereby ourselves. Otherwise, it is conceivable that man himself may become an endangered species.

H Kanus-Photo Researchers

He[illegible] is one of the major sources of air pollution. Here steel mills befoul the air in a city in Japan, causing poor visibility over a large area

AIR POLLUTION

"Our city is a wonderful place to live in; where else can you see the air you breathe?"

Have you heard this joke? It isn't very funny. Smoke-filled air in drab shades of yellow, brown, or gray is common in cities all over the world. The gases and particles that reduce visibility also damage trees, ruin clothing and other materials, cause your eyes to smart, and increase your chances of developing a respiratory disease.

But there are other types of air pollution that are even worse. Every day our cars, our cities, and our industries pour a number of invisible substances into the air. These may not have any immediate bad effects. But over a period of years, breathing such air may make you seriously ill and may even cause your death.

MANY POLLUTANTS

What is air pollution? It is the presence of substances that are not normally part of the atmosphere's composition. There are many kinds of air pollutants: smoke, dust, ash, pollen, various gases, and other substances. Many of these come from sources other than man and his activities. They have always been present in the atmosphere. They come from the ground, from activities of plants and animals, and even from outer space (meteoritic dust). These pollutants are seldom harmful. Indeed, they are often beneficial. Without atmospheric dust, for example, rain and snow would never fall.

Nature easily handles her own forms of air pollution. Heavier pollutants soon settle out of the air. Rain, one of nature's most effective "antipollution devices," washes dust and other pollutants from the atmosphere. Finer particles and gases may remain airborne indefinitely, becoming spread far and wide through the atmosphere.

Our activities threaten this natural system of checks and balances. Chimneys, incinerators, factories, airplanes, and automobiles are discharging pollutants into the air at an ever-increasing rate. Many scientists fear that the cycles of the earth and

National Air Pollution Control Administration

Stone and other building materials are not immune to the effects of air pollution, as this statue of Alexander Hamilton in Washington, D.C. illustrates.

the atmosphere may not be able to cope with this increased pollution.

Air pollution caused by human activities is reaching dangerous concentrations in many parts of the world. It already presents a very serious threat to our well-being and the survival of other life on earth.

CLASSIFYING AIR POLLUTANTS

Solid and liquid pollutants exist in the form of very small particles, or *particulates*, that are light enough to remain in the air for some time. Solid particulates include dust, soot, and ash. Of increasing concern to health authorities are particles of metals, including lead and lead compounds, nickel, cadmium, and beryllium, that get into the air. Liquid particulates include mists and sprays.

The most familiar form of air pollution—*smoke*—is a mixture of particulates and gases. *Smog* is a combination of smoke and fog, but the term is also applied to certain other types of visible air pollution.

Inorganic gases include oxides of nitrogen, oxides of carbon, oxides of sulfur, and substances such as ammonia, chlorine and hydrogen sulfide.

Organic gases include hydrocarbons such as methane, benzene, acetylene, an ethylene; aldehydes and ketones; and con pounds such as benzopyrene, alcohol, an organic acids.

The number and variety of air poll tants are steadily increasing as man d velops and uses new chemicals. The chemicals, plus waste products from ind trial processes, enter the atmosphere varying degrees.

SOURCES OF AIR POLLUTION

One of the major sources of air p tion is the internal-combustion engine engine, used in most motor vehicles, d not burn all its fuel. Thus, in additio emitting water, carbon dioxide, and vari oxides of nitrogen, it gives off a numb incompletely burned waste products. T include soot (carbon), carbon mono hydrocarbons, and aldehydes. Aut gines may also emit particles of lea rived from the antiknock ingredient many gasolines.

In the United States the catalyti verter and other emission-control de on automobiles constructed since have reduced the carbon monoxide en sions. The mandatory use of lead-free g oline in vehicles thus equipped has a reduced the emission of lead particles i the atmosphere.

In the presence of sunlight the nitrog oxides and hydrocarbons often combine t produce irritating smog-forming com pounds. Los Angeles is particularly well known for the automotive smogs that have plagued it since the 1940's. But other cities around the world are suffering similar, or worse, problems as a result of man's dependence on the automobile.

Jet aircraft also release large amounts of pollutants into the atmosphere. You probably have seen the long trail of black smoke left behind by a climbing jetliner. Many aircraft pollutants are the same as those emitted by automobiles and trucks. Some experts are particularly alarmed by the large quantities of water and carbon

dioxide being added to the atmosphere at high altitudes.

Exhausts from railroad trains and ships also pollute the atmosphere. But transportation is not the only source of serious air pollution. Industry and electric-power-generating plants are major contributors. So is the burning, or incineration, of solid wastes. Agricultural burning, coal-waste fires, and forest fires also befoul the atmosphere.

EFFECTS ON HEALTH

Can air pollution kill you? There is little doubt that it is at least a contributing factor in deaths from diseases such as emphysema and lung cancer. Evidence also indicates a strong relationship between air pollution and cardiovascular deaths, bronchitis, and all types of cancer. Death rates among elderly people or those who already have respiratory and heart ailments increase sharply during periods of high air-pollution levels. Metallurgical workers who inhale cadmium fumes may die of cadmium poisoning. Construction workers who have inhaled asbestos fibers may develop scarred lung tissue and lung cancer.

In addition, we know that air pollutants irritate the eyes, throat, and lungs, causing sore throats, coughing, and so on. Children living in areas with high air-pollution levels have a greater incidence of asthma and eczema and other skin diseases than do children in less-polluted areas. Of equal or greater concern to doctors are the long-term effects of pollution on children. Will pollution increase their chances of contracting a chronic or lethal disease later in life? Scientists cannot answer this question. Nor do they yet know the effects of pollutants on heredity and on prenatal life. But as they explore these and other questions, they are learning many disturbing things.

Any particulate matter that collects in the lungs may be dangerous. If enough accumulates, it interferes with breathing, causes tissues to deteriorate, and may lead to death. This problem is especially serious among miners. Silicosis is the most common dust-related disease. It results from inhaling quartz dust or particles of other silica-containing rocks. Miners of coal and ores such as gold, iron, lead, and copper are often exposed to large amounts of silica-containing dust. Thus they are very susceptible to silicosis. Workers in various foundry jobs, china and pottery making, sandblasting, and granite carving also run a risk of contracting the disease.

United States Environmental Protection Agency

Helicopter passing a tetroon, a helium-filled balloon that is used to mark off sections of air to be tested for pollution

Heavy industry is often concentrated near ports. Besides the pollution of waterways in these areas, air pollution is often a problem

Stock, Boston, W. B. Finch

Other serious dust diseases include black-lung disease (from inhaling coal dust), berylliosis (from beryllium dust), byssinosis (cotton dust), and asbetosis (asbestos fibers).

EFFECTS ON PLANTS AND BUILDINGS

Human beings are not the only living things harmed by air pollution. Many plants are also damaged. In fact, the effect on vegetation is often a clue to the existence of air pollutants that are not noticeable in other ways. Carbon monoxide, hydrocarbons, sulfur compounds, metals, acids, and ozone are serious threats to most vegetation. Plants absorb these pollutants through their leaves. The leaves may develop holes, become discolored, or wilt. Eventually they may die. This may lead to the death of the entire plant.

Other undesirable effects of air pollution include the damage done to buildings and materials. Sulfur pollution causes steel, zinc, and building stone to corrode. Ozone damages rubber and textiles and discolors dyed materials. Particulate matter makes necessary the frequent painting of houses, cleaning of clothes, and washing of cars.

EFFECT ON WEATHER AND CLIMATE

Scientists have definitely established a relationship between air pollution and weather. Each can affect the other in a variety of ways.

Wind and temperatures, for example, affect the quantity and extent of pollutants in the air. Strong air currents may disperse pollutants in both vertical and horizontal directions. Although this decreases pollutants in an industrial region, it also carries them to places far removed from the factories.

Sometimes the reverse happens. A layer of cold air near the ground is trapped by a layer of warmer air over it. This is called a *temperature inversion*. There are no strong air movements and no marked weather changes for several days or even weeks at a time. The air near the ground becomes filled with pollutants. A crisis may result. In 1970, for example, a dense smog blanketed Tokyo for a week. More than 8,000 people had to be treated for burning throats, smarting eyes, and other ailments caused by the polluted air.

Two pollutants may have major effects on climate: carbon dioxide and particulate matter. Carbon dioxide tends to trap heat in the lower atmosphere. Particulate matter has the opposite effect: it reflects solar heat back into space. A marked increase of one or the other could cause a worldwide warming or cooling trend.

A good example of the local effects of pollution on weather is the increase in rainfall found in cities and in regions adjacent to, or downwind from, large paper mills. Particles from the mills act as nuclei around which raindrops form.

CLEANING UP OUR AIR

A variety of international, national and local programs have been instituted in an effort to combat air pollution. These programs are primarily concerned with establishing and then enforcing regional air quality standards.

As a result, industry is being forced to develop cleaner and more efficient furnaces, engines, and methods. Particulate matter can be removed from factory, home and auto emissions by a variety of filters, by washing or scrubbing devices, and by electrostatic precipitators. Some gaseous emissions, such as hydrogen fluoride and oxides of nitrogen, are soluble in water and thus comparatively easy to recover. The air containing these contaminants is passed through water in bubble towers, scrubbers, or other devices. Other gases, such as certain hydrocarbons, can be removed by adsorption on activated charcoal. The best way to prevent carbon monoxide pollution is to ensure the complete burning of fuels. Sometimes, a would-be pollutant can be recovered and reused.

Some antipollution procedures are costly. But the effects of air pollution are far more costly, both economically and medically. As we dump more and more wastes into the air, we increase the chance of death, both from disease and from the destruction of the complex ecological systems on which man and all other forms of life depend.

Michael Melford/Wheeler Pictures

A sci... tends a field installation for collecting rain samples in a northern fores... ...mples are tested immediately for acidity.

ACID RAIN

by Ian Nisbet

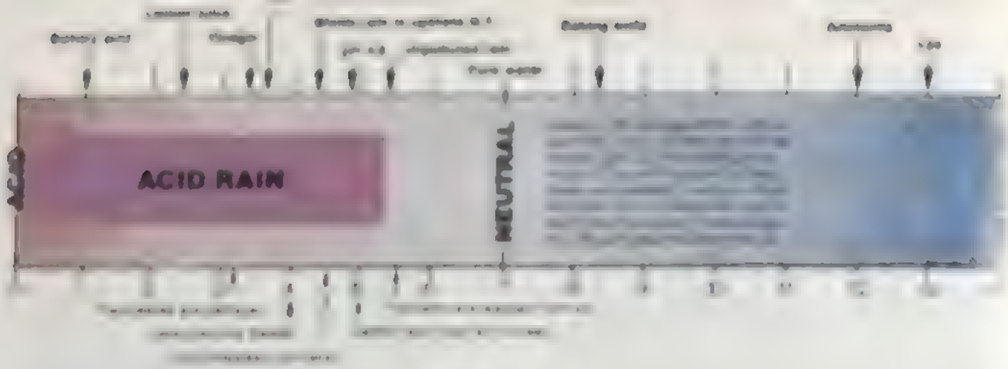
On a bright morning in the fall of 1981, the sun sparkled on the clear waters of Spirit Lake in New York's Adirondack Mountain Wilderness. For generations, fishermen have been drawn to this lake and to the streams that flow into it from the surrounding mountains. But this year there are no fishermen on the shore, and the cabins around the lake are silent and empty. For there are no longer any fish in Spirit Lake.

Far across the globe, the same scene is repeated in the valley of the Tovdal River in southern Norway. Once famous for the salmon that swam up the river each spring to spawn, this valley is now an environmental tragedy. For the salmon no longer return, and the river is almost empty of life.

We usually think of pollution as a problem of cities and industrial areas. Lakes and streams in the mountain wilderness are the last places we would expect to be badly polluted. But Spirit Lake, the Tovdal River, and hundreds of other remote lakes and rivers are affected by an unusual form of pollution. The fish are gone because the water has become too acid for them to live. And the acid comes from the sky, in the rain in the summer and in the snow in the winter.

SOURCES OF ACID RAIN

Acid rain is caused by industrial activities that pollute the air. The main sources are electric power plants that use the energy produced by burning coal to generate electricity. Most coal contains small amounts of sulfur, which is converted to *sulfur dioxide* when the coal is burned. Although most power plants use precipitators to remove small particles from the coal smoke, sulfur dioxide is a gas and passes



pH SCALE

downwind. Other important sources are the power plants, refineries, and automobiles in the coastal states between North Carolina and New York. In the West, smelters of nonferrous metals and emissions from autos and trucks are the major sources.

THE UNFORTUNATE HISTORY

The problem of acid rain started in the early 1950's. At that time the first serious attempts were being made to clean the air of our cities by reducing levels of sulfur dioxide and smoke. These involved stopping the burning of coal to heat homes, converting power plants in cities to burn oil or gas, and fitting power plants with precipitators to remove solid particles (known as "fly ash") from the combustion gases. As new power plants were built, they were located away from cities and were equipped with tall chimneys—often more than 150 meters high—to disperse the sulfur dioxide, so that it would not reach the ground in high concentrations.

These pollution-control measures were quite effective in reducing levels of smoke and sulfur dioxide in the cities, but the total amount of sulfur dioxide released into the air continued to increase as growing population and rising demand for electricity led to the building of many new power plants. Worse, the building of tall chimneys meant that most of the sulfur dioxide remained in the air for a longer time after it was released, so that more of it was converted to sulfuric acid. Another factor was that the fly ash removed by the precipitators was alkaline, so that the airborne acid was no longer neutralized by it. The result was a rapid increase in the acidity of rain during the 1960's.

Under current rules, most new power plants must install equipment to control the amount of sulfur dixoide that is released. Nevertheless, older plants continue to emit sulfur dioxide, nitrogen oxides remain even more difficult to control, and the problem of acid rain continues to worsen.

WHAT ACID RAIN DOES

When acid rain falls to the ground, part of the acid is neutralized in the soil, and the water that runs off into streams and rivers is usually less acid. Some soils—particularly those formed from limestone rock—have a large capacity to neutralize the acid. Soils formed from granite rocks, however, are already acid, and their capacity to neutralize acid rain can be used up within a few years. This has happened in some areas in the northeastern United States, in parts of eastern Canada, and in southern Norway and Sweden. In these areas, streams and lakes have become too acid to support fish and other life.

Sulfuric and nitric acids carried in rain and snow caused these brook trout to suffocate and die in a test cage placed in an Adirondack stream.

Rapid change in water chemistry following the first melting of acid-laden snows in spring destroys some fish life. As an area becomes more acidified, fish are unable to reproduce and gradually disappear. Amphibian eggs, such as those of salamanders, laid in acidic ponds and meltwater pools, fail to develop properly. At the same time the variety and number of small aquatic plants is reduced. Larger plants such as water lilies may disappear while acid-tolerant mosses and algae may form dense mats sealing out oxygen and further disturbing the freshwater ecology. Eventually, a lake or stream becomes almost lifeless, with its water unnaturally clear.

Acid rain also changes the chemistry of natural systems. It leaches important nu

WILDERNESS

NOW PROTECTED BY LAW

Wilderness areas in the United States were finally given the protection of law with the passage of the Wilderness Act of 1964 which placed 3.7 million hectares in 54 areas in the National Wilderness Preservation System. The act also made provisions for the addition of other areas, and today the system includes more than 4.9 million hectares in 125 areas. These areas are under the jurisdiction of the U.S. Forest Service, the U.S. National Park Service, and the U.S. Fish and Wildlife Service.

Under the act, a wilderness is defined as ". . . an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." The act further defines wilderness as land ". . . retaining its primeval character and influence . . . and which . . . generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable."

FIRST SURVIVAL

The passage of the Wilderness Act signalled that after more than 350 years of settlement and development, the American attitude toward the wilderness had been officially reversed. The early settlers, fear ul of the Indians and other unknowns be hind the wall of trees fringing the shor had kept their settlements practically on t beach. The pressures of simple surviv building and keeping a safe home, hav enough food – effectively kept the sett from having any sense of the scenic be of the land that was gradually being clear

Then, too, the amount of land se unlimited, even with the Eastern seal area quickly becoming developed and tively overcrowded. As the states admitted to the Union, they ceded their claims to western lands to the f government. The Louisiana Purch 1803 pushed the boundaries of the co still farther west – to the Rocky Mount It seemed almost an excess of land 1812 the General Land Office was lished to dispose of it.

Incentive grants were given to t roads, and other land was sold at ver prices to those who later would Western timber barons. Land was given away or sold to all those wh agree to irrigate, mine, or plant tre The bargains were incredible, and were so many takers that the phras a land office business" was coined.

The greatest depletion of Am

Mangrove swamp in Florida's Everglades National Park, one of the parks. Mangroves are one of the few plants that can tolerate seawater

wilderness came in the late nineteenth century. The Homestead Act of 1862, with its guarantee of 64 hectares to those who would work it and live on it for five years, spelled opportunity for many in the crowded East, and thousands rushed westward to take advantage of it. Bison, once numbering in the millions, were threatened with extinction by the 1880s, and by 1891, the historian Frederick Jackson Turner was saying that the frontier was closed.

BUT SAVE SOME LAND

It was during this time that the first efforts were made to save part of the land for future generations, although not so much in the spirit of preserving natural resources as of protecting its curiosities of nature. In 1864 the Yosemite area of California was withdrawn from development, and in 1872 Yellowstone was established as the first national park. In 1891 the U.S. Congress authorized the president to set aside lands from the public domain to be called *forest reserves*. These were the precursors of the national forests, established in 1905 by President Theodore Roosevelt.

By the time Roosevelt became president in 1901, his predecessors, Benjamin Harrison and Grover Cleveland, had set aside 13.7 million hectares. Roosevelt added 53.4 million hectares to the forest reserves. He also established 51 national wildlife refuges and designated 18 areas, among them the Grand Canyon, to be national monuments. By the time he left office in 1909, conservation was both a new word in the vocabulary and a movement.

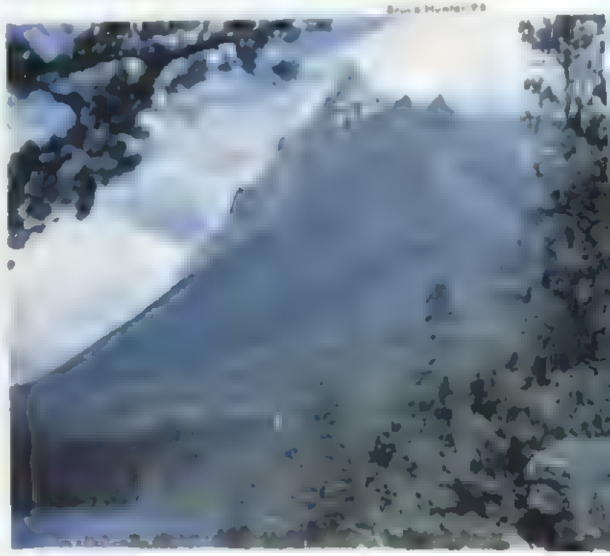
FOR USE OR FOR BEAUTY?

President Theodore Roosevelt was greatly influenced by Gifford Pinchot, first head of the U.S. Forest Service, and the man whose ideas formed the beginnings of the conservation movement. Pinchot was well aware that America's forest resources were limited, but he was determined to use them at the same time that he was preserving them for the future use of others. To do so, he developed a system that permitted the use of the forest for various purposes—timber production, mining, watershed management—but at the same time required a scientific approach that would take into account the renewal of the resources. This is the concept of *multiple use*, and it is yet today the favored form of forest management by the Forest Service.

Without Pinchot and his ideas, there probably would be very little wilderness today. However, the contemporary concept of wilderness is based primarily on an appreciation of its scenic beauties and opportunities for rest and pleasure. These were considerations that Pinchot relegated to second position. It was John Muir who was in large part responsible for the change in attitudes.

The founder in 1892 of the Sierra Club, Muir spent much of his life wandering alone through the wilderness and in particular through Yosemite. He was a popular writer, whose unique life style and vivid descriptions of his wanderings gave him wide readership. He was a friend of Pinchot, but the two eventually fell out over the differences in their priorities. Muir thought recreation the only legitimate use

Going-to-the-Sun Mountain in Glacier National Park in Montana. The park is part of the U.S.-Canada Waterton-Glacier International Peace Park. More international cooperation is needed to preserve wilderness areas.



Weyman/PR

Brown pelicans watch over Pelican Island Wilderness from their lofty nests. Wilderness areas are home to many species, including some endangered species.

of the wilderness. He defined recreation as including both physical and mental activities, but excluding any activities which required that facilities be built. He opposed roads, logging, mining, and grazing. He was ahead of his time and did not receive immediate acceptance of his ideas as did Pinchot. Only after his death did Muir's ideas begin to have an effect on wilderness planning.

FIRST WILDERNESS AREAS

The preservation of wilderness areas was begun in the 1920s by the U.S. Forest Service. The Service was, however, at first unreceptive to such proposals. Arthur G. Carhart, who wrote the first paper describing the wilderness concept, resigned from the Service in 1923 because he could not get the kind of action he thought necessary. Nevertheless the Service established the Gila Wilderness in 1924. Its conception and development was the work of Aldo Leopold, who was one of the first to recognize that the use of wilderness as a recreational resource was just as valid and important as its other uses.

Further steps were taken in 1929, when provisions for establishing primitive areas were set up, and then again in 1939, when certain laws, known as the "U" Regulations, allowed for the establishment of wilderness areas. Through these provisions 5.6 million hectares were eventually protected. Although grazing and mining were allowed on the lands, other development such as logging and hunting or fishing lodges was not. The "U" Regulations were enacted largely through the work of Robert Marshall, a long-time employee of the Forest Service and the founder of the Wilderness Society in 1934. He was quite influential, and the Forest Service followed a more-or-less preservationist stance during his years of service. The outlook changed however, following his death in 1939.

A LONG STRUGGLE

The Forest Service then became mu[illegible] more concerned with timber producti[illegible] and multiple use, especially after Worl[illegible] War II, and the conservationists who ha[illegible] put their trust in the Forest Service to sa[illegible] the wilderness began to look elsewhere f[illegible] support.

They found Howard Zahniser, a ti[illegible] less advocate of the wilderness cause. In [illegible] speech in 1955 he proposed protection [illegible] wilderness by law. This speech gave nationwide attention to the growing movement. The first wilderness bill was introduced in Congress the following year. Between then and its signing in 1964, the bil[illegible] was rewritten several times, the subject [illegible] 18 public hearings, and was heavily opposed by the forest, oil, grazing, and mining industries.

In 1960, with the fate of the wilderness bill still uncertain, the preservation movement suffered another setback with the passage of the Multiple Use and Sustained Yield Law. Basically, the law allowed the Forest Service to do what it wanted with the national forests, as long as it was within the act's definition of their purpose. Only a last-minute compromise included a mention of wilderness preservation as being consistent with the purposes of the national forests. This situation pointed up the need for legislation protecting wildernesses. The Forest Service could establish wilderness areas, but it could just as easily remove that classification should it decide to use the land for some other purpose.

The Wilderness Act of 1964 was final-

ly passed and signed, however, and although it too was a compromise, this time the main objective had been won—wilderness was now preserved under law as forever free from the influence of man.

MOUNTAINS TO EVERGLADES

The word wilderness often calls to mind dense, evergreen forests covering the slopes of rocky, snow-covered mountains, but such terrain is only part of a wide range of wilderness, which in the United States also includes tundra, grasslands, deserts, and subtropical everglades. Wilderness areas are located in all parts of the United States, although primarily in the West, and range from the 1.2 hectare Pelican Island Wilderness in Florida to the Selway-Bitterroot, sprawling over more than 502,000 hectares of the Idaho and Montana Rockies.

The Selway-Bitterroot area protects within its borders cliffs, lakes, mountain peaks, streams, valleys, and forests and offers a wide variety of recreational activities, including canoeing and rafting down the rapid Selway River. Across the country, canoeists paddle through Maine's Allagash Wilderness Waterway, struggling through white water, portaging around falls, and floating through lakes.

Water is not one of the more available commodities of the Superstition Wilderness, located close to Phoenix, Arizona. A desert environment of sheer cliffs, dry valleys, and cactus, fringed by the Superstition Mountains, it enjoys a pleasant climate for much of the year, although the summer brings sudden thunderstorms and burning heat. As in the Selway-Bitterroot, there is a well-developed trail system. The immense solitude of the rugged and desolate land, together with the joy found in discovering and contemplating the often minute forms of life inhabiting it, are the chief attractions.

Shining Rock, near Asheville, North Carolina, is a gentler wilderness. Waterfalls tumble from mountain ridges, and deciduous forests cover the slopes. Further north, Dolly Sods is an excellent example of an area that has reverted to wilderness after years of forest fires and extensive logging. Located on the Allegheny Plateau, the land has a character and climate more nearly that of Canada than of West Virginia. Open meadows surrounded by high ridges contain sphagnum bogs, blueberry patches, and a variety of wildlife.

Wilderness areas, as opposed to national forests and parks, are roadless, and usually the only way into them is by trail. However, the only way into the Okefenokee National Wildlife Refuge in Georgia and Florida is by canoe. A vast swamp, the area is lush with cypress forests, open marsh, and stands of southern hardwood. Alligators, bears, birds, and mosquitoes are in abundance.

Access is limited into the Okefenokee in another way too, as entrance permits are required. Such practices are becoming increasingly common as wilderness use has become the fastest growing form of outdoor recreation. Other limits on human use of the wilderness are also being established and include prohibitions against wood fires and requirements that trash be carried out and not burned or buried. The length of time a person is permitted to stay in the area is now also often limited. Those wishing to enter a wilderness area should therefore check with its supervisors before planning a trip.

Wilderness travel, where hiking to the

Impala roam free in South Africa's Kruger National Park, the largest sanctuary of its kind. The park has served as a model for many game reserves in other parts of Africa.

next campground can be rough going, is not for everyone, and certainly not for the novice to the outdoors. But for those who are interested and able, it can be one of the most rewarding of experiences. Hiking, camping, fishing, canoeing, and climbing are its chief physical attractions, but represent only one part of its attractions. Such activities as examining the shape of a leaf, watching the sun set over a placid lake, or searching out constellations in a star-laden sky are some of the often intangible joys discovered in a wilderness experience.

OUTSIDE THE UNITED STATES

Once outside the borders of the United States, the term wilderness takes on many different meanings, with the definition often changing from country to country. The United States is the only nation with laws specifically protecting wilderness, as distinguished from national parks or nature conservancies. But almost every other nation has set aside part of its land in one form or another—nature conservancy, wildlife refuge, or national park. The 1975 United Nations List of National Parks and Equivalent Reserves lists 117 national nature reserves, 991 national parks or their equivalent, and 224 provincial parks in the world.

In comparison with wilderness areas in the United States, many of these areas tend to be smaller, more oriented to the preservation of wildlife, and more restrictive of the general public. Many have roads within their borders, and some have facilities for tourists. The idea for creating such reserves is not new, and dates to the times when European royalty set aside forests for their own use in hunting and as a source of food. The catalyst for the development of many reserves, however, was the creation in 1872 of Yellowstone National Park.

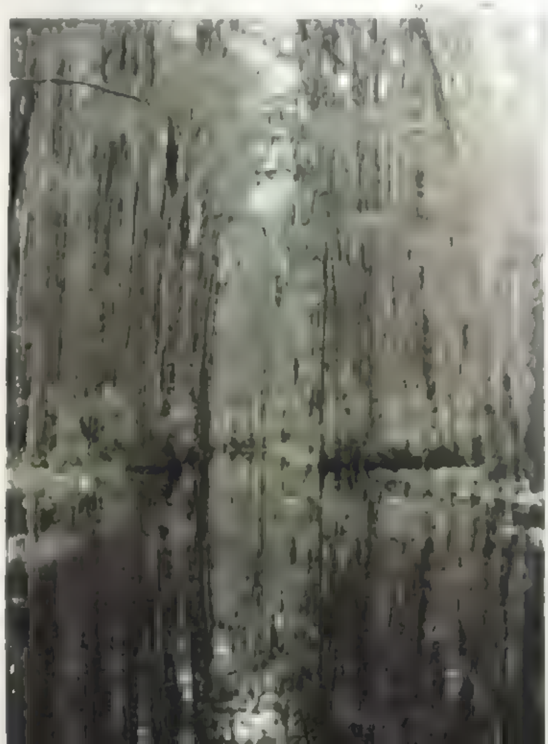
Much has been accomplished outside the United States since that time. Canada created Banff National Park, its first, in 1887, and established its National Parks Branch in 1911, five years before the United States. Mexico, which established its first forest reserve in 1898, is today in an excellent position to add to the areas already protected, as much roadless wilderness remains, and most of it is publicly owned.

Kruger National Park, in South Africa has served as the model for many of the vast game reserves and national parks that spread over Kenya, Tanzania, Zaire, Uganda, Rhodesia, and other African nations protecting the vast numbers and variety of wildlife roaming their open plains. Although poaching remains a serious problem in Africa as well as other parts of the world most shooting now is done with a camera Kruger National Park, although first se aside in 1898, was not opened to the publi until 1927 in order to give the almost exte minated animals a chance to multiply.

China, in a reversal of a policy that u til the late 1960s encouraged the killing the Chinese tiger, is now protecting it alon with 31 other species, including the gia panda. A system of national parks and r serves is planned for the South Pacific.

The United Nations Education Scientific, and Cultural Organizat (UNESCO), as well, has announced a s tem whereby certain jungles, mountain

Spanish moss-draped cypress trees are a featur the Okefenokee National Wildlife Refuge, lyin Georgia and Florida



and deserts will be set aside, off-limits to human intervention, as laboratories for scientific study. These living laboratories will be called *biosphere reserves*.

WILDERNESS PRESERVATION—A LUXURY?

Some of the approximately 10 per cent of the world's remaining wilderness, however, will doubtless be lost before it can be saved, and nowhere is the problem more acute, or difficult to resolve, than in the developing nations. In the face of food shortages, lack of available land for farming, and the absence of adequate health and educational systems, the preservation of land is often seen as both a conflict of priorities and a luxury. An increasing number of developing nations, though, are realizing that the time to save the land is now, before it has a chance to be developed, and progress is being made. India, for example, is setting aside 0.4 per cent of its land as parks and sanctuaries, and Nepal is planning to establish four national parks and wildlife reserves in its mountains.

Kenya's favorable experience with tourism—it is now its largest industry—has provided the impetus for some of the newfound interest in preservation in developing nations. Potentially large revenues from tourism are seen as a means of bringing in needed foreign currency and of providing a replacement for the monetary value that the land would bring were it farmed or otherwise developed.

INTERNATIONAL EFFORTS

Preservation remains expensive, however, and many nations set aside land only to find they do not have the funds to maintain or protect it adequately. The job is too big for all but the most highly developed nations, and so international organizations are playing an increasingly large role in the conservation of both land and wildlife. The World Wildlife Fund (WWF), organized in 1961, channels the money from its fundraising into such projects as saving the white rhinoceros in Uganda and research on the giant tortoises of the Galápagos Islands. It has been a worldwide organizer of

M. Woodbridge Williams, U.S. National Park Service

Mesas, or plateaus, in Canyonlands National Park in Utah. The park was established in 1964, the Year of the National Wilderness Protection Act

the drive to save the tiger from extinction. The International Union for the Conservation of Nature and Natural Resources (IUCN) promotes the conservation of wildlands and wildlife, and maintains lists of both endangered species and national parks. The United Nations Environment Program (UNEP), as part of its global program of environmental activities, works for the preservation of land and wildlife through research, education, support, and advice. All three groups work together on various projects, exchanging information and pooling resources. The WWF and IUCN, for example, are working together to save the world's tropical rain forests, and all three cooperate closely to save endangered species.

In some areas of the world, though, the time has long since passed when wilderness areas could be preserved. There is virtually no wilderness remaining in Europe. Even in its high mountain country, where villages

M. Woodbridge Williams, U.S. National Park Service

Canoeing is popular along the Allagash Wilderness Waterway in Maine. Logging operations had damaged the area, but it is now recovering. The forest is home for moose and other wildlife.

and ski resorts dot the landscape, few views are without evidence of development. The only resemblance that the nature conservancy areas of Great Britain, limited in size and on land that has been used for centuries, bear to wilderness areas of the United States is in their similar goals.

But there are still large parts of the world—Central America, for one—in which large areas remain roadless and undeveloped. Others, like the tropical forests of North Sumatra, have only recently been mapped. It has been just in the past few years that the Transamazon Highway and new dams on Amazon River tributaries have seriously threatened Brazil's rain forest, but with care it may be saved.

NOT COMPLETE PROTECTION

Considering that a large portion of the world's wilderness areas was lost before the conservation movement began, a good start has been made. But wilderness still is not secure, and in some cases not even where it is protected. In the United States, for example, the Wilderness Act of 1964 included compromises that potentially could destroy the value of the land as wilderness. Mining is allowed on existing rights until the beginning of 1984, grazing and the use of aircraft and motorboats were already established, and the president may authorize the construction of power lines and reservoirs if in the public interest. New areas studied for inclusion in the system are subjected to often intense lobbying by those who would hope to develop the land, and these lobbies are frequently more powerful than conservation groups.

Even recreation is proving a threat Much wilderness land is fragile and cannot support the droves of people who flock to it. In Africa cars and vans form circles around wild animals as tourists snap pictures.

Awareness of the need for wildernes as a recreational, scientific, and education resource is growing, though. In the Unit States since the Wilderness Act of 19 was passed, other pieces of related legisl tion have been enacted. These include th Rare and Endangered Species Act of 196 the Wild and Scenic Rivers Act of 196 the Eastern Wilderness Act of 1974, a the Alaska Lands Act of 1980. A number states have also passed protective laws

The fight to save the wilderness is from won, and probably never will be, but start has been made. At least some of t world's wilderness is more secure tod than it was just a few years ago.

Wild rocky shores are among the scenic pl sures of the islands making up Acadia Natio Park on the rugged coast of Maine in the U

Richard Frear U.S. National Park

ENDANGERED SPECIES

by Richard G. Van Gelder

The tiger pacing back and forth in his cage and the polar bear paddling around his small pool in the zoo may soon be the last living representatives of their species. Along with other zoo favorites, such as the orangutan and the gorilla, tigers and polar bears are threatened with extinction—with total disappearance as living species—unless man comes to their defense with strict protective measures.

Throughout the world, in ever-shrinking wilderness areas, wild animals are making a last stand against the ravages of man. From the gorillas of central Africa and the vicuñas of the Andes to the kangaroos of Australia and the whales of the open seas—everywhere there are animals whose survival hangs in the balance.

Although most of this article is devoted to a discussion of endangered animals, we will also consider some plant species that are threatened and which until recently were often ignored. Action to save both plant and animal species is of utmost importance for future generations as well as for ourselves.

EXTINCTION AND EVOLUTION

Extinction is nothing new. Ever since life appeared on earth about 3,000,000,000 years ago, animals have lived and died, species have evolved and become extinct. Dinosaurs ruled the earth for eons and then became extinct. Just why and how no one really knows. Extinction is a part of the process of evolution. Animals either adapt or fail to adapt to changes in their environment. The price of failure is extinction.

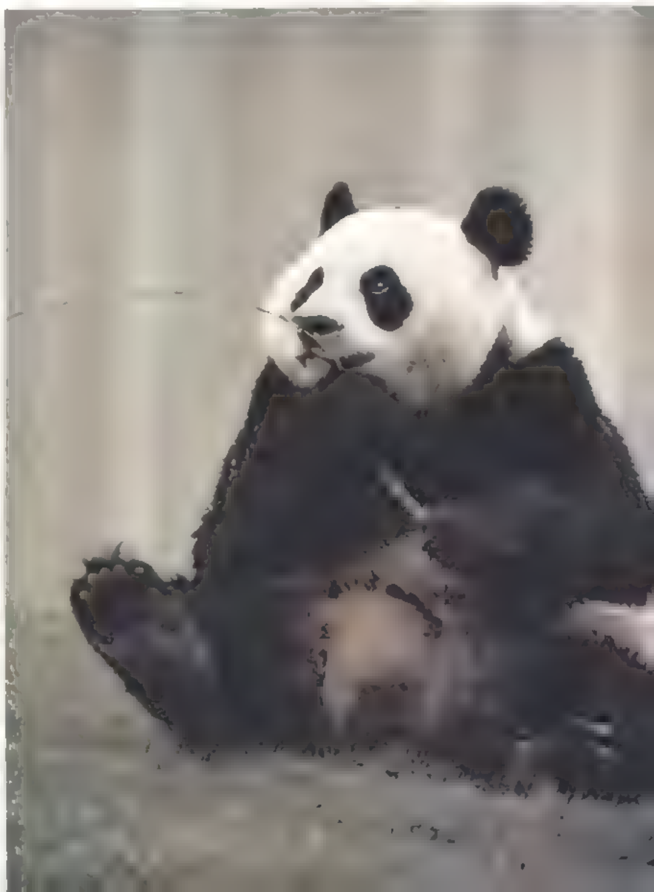
In the past, however, these environmental changes took place relatively slowly, over thousands or millions of years. Those species that were successful in adapting to a particular change, such as a gradual cooling of the climate, survived. Those that could not develop the necessary internal, external, or behavioral characteristics became extinct.

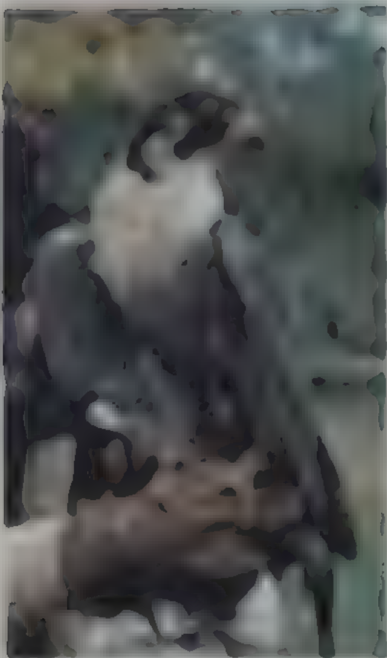
INTERACTIONS AMONG SPECIES

In the past one species probably did not directly cause the extinction of another. For example, it is doubtful that a meat eater would devour all members of a species on which it preyed. If this did happen, then the meat eater might also become extinct, because it would then have no food. Generally, a balance is established between the populations of the predator and the prey. For example, when the number of snowshoe hares in Canada is very high, the lynxes feed well and more of their young survive.

The giant panda. A native of western China, this animal may grow to nearly two meters long and weigh up to 90 kilograms. The panda's diet is extremely limited; it feeds only on plants, such as these bamboo shoots. The giant panda is now protected by law from hunters, but the species is very rare and may die out if it does not adapt its diet to include other kinds of plants and animals

[illegible] B Kat[illegible]





thought to be in some danger of extinction. Many of these are found on islands, particularly on the islands of Indonesia and on Madagascar.

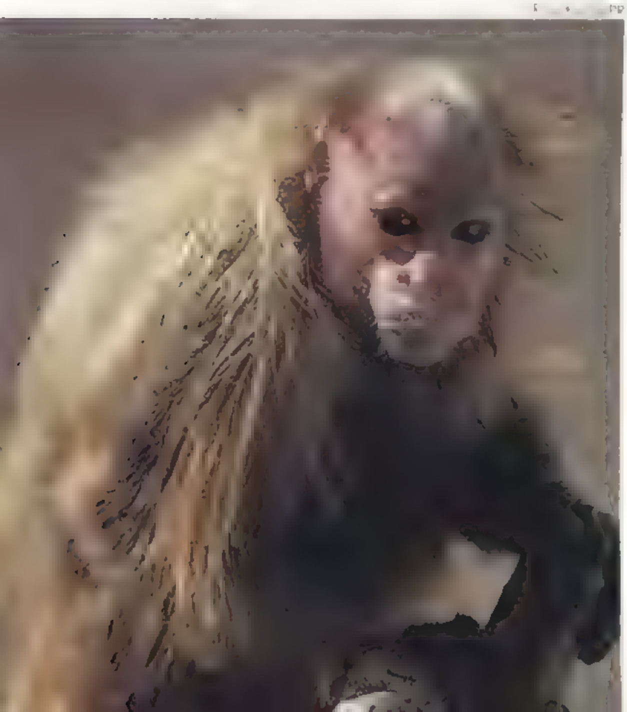
BIRD SPECIES LOST

The pattern is the same for birds as for mammals. Of the almost 8,700 species of birds living in 1600, 94 have become extinct. Among the living species, 187 are now in some danger. Again, it is the islands that have suffered most—New Zealand, Madagascar, Guadalupe (Mexico), Rodrigues (Indian Ocean), the West Indies, and the Hawaiian Islands have each lost several species.

In North America the two most tragic extinctions were the Carolina parakeet (*Conuropsis carolinensis*) and the passenger pigeon (*Ectopistes migratorius*), the last representative of which died in zoos in 1914. Both species originally existed in such vast numbers that they darkened the skies when they migrated.

MANY PLANT SPECIES ARE THREATENED

Although almost all the publicity in recent years has involved endangered animals, there are also many species of plants that are threatened with extinction. In fact, 20,000 species, or about ten per cent of all



flowering plants, are now in some danger Again, it is man and his activities that constitute the most serious threat. New animals and plants are introduced into areas and overwhelm the native species. Also increasing amounts of land are cleared fo farming, which destroys native vegetation.

If these threatened plant species ar allowed to disappear from the earth, th consequences for mankind could be seri ous. Some scientists feel that the disappea ance of these plants could be more impo tant than the loss of the endangered anim species.

Many drugs are obtained from plant and it is very likely that some of the threa ened plants contain chemical compoun that would be medically useful. Othe could possibly be of economic importan as food crops, timber trees, or even as orn mental house and garden plants. Since f if any, of these plants have been scree for possible use as drugs, and since i impossible to know what future crop ne may be, it is important to keep these thre ened plants alive.

Among plants, as among mammals a birds, island-dwelling species are the m vulnerable to extinction. In many cases t plants found on an isolated island are n found anywhere else in the world. The troduction by man of plant-eating anima particularly goats, has almost complete destroyed the native vegetation of seve islands. In the process, a number of plan species have become extinct, and man others have become very rare. The situa tion in Hawaii, for example, is very seriou It is estimated that 80 per cent of the state higher plants are threatened or rare.

Certain forest plants have also been threatened, and some are already considered endangered or extinct. Among these forest plants are several species of orchids found in Brazil and India, as well as a crocus that is native to Chile. Cacti in the

Some of man's nearest living relatives—primates—are also in danger of extinction. Left: the uakari, a short-tailed monkey native to South America, now seriously endangered. Right: the mountain gorilla Because of disease and destruction of its habitat, it too is becoming increasingly rare

southwestern United States are also in danger. About 26 per cent are threatened or endangered species.

Because of the increasing danger to plants and growing concern about them by conservationists, the International Union for the Conservation of Nature and Natural Resources (IUCN) is putting out a volume of the *Red Data Book* for flowering plants. However, this project is relatively new, and it will take many years to complete.

CLASSIFICATION OF THREATENED SPECIES

Many plant and animal species are threatened by the possibility of extinction. However, the seriousness of this threat varies. For example, a species with fewer than 50 known survivors living in one small area is in much more critical condition than another with 5,000 individuals living in several areas.

The Survival Service Commission of the IUCN has established four categories to describe the degree to which a species is threatened with extinction. These categories are endangered, rare, depleted, and indeterminate.

Endangered species. A species is considered endangered when its numbers are so few or its homeland so small that it will probably disappear forever if not given special protection. The Taşmanian wolf *(Thylacinus cynocephalus)* is such a species. It is a marsupial (pouched mammal) with a doglike body and wolflike habits. It once inhabited Tasmania and much of Australia. Its disappearance from Australia probably resulted from competition with dingoes and domestic dogs. It was also hunted and killed by sheep ranchers. Much of its habitat was destroyed, and distemper, a contagious disease of dogs and other mammals, greatly reduced the number that remained in the early 1900s. Although a few may have been seen in recent years and some may persist in the wilder, more remote parts of western Tasmania, no one knows how many – if any – Tasmanian wolves are living. The animal has never bred in captivity, and the last zoo specimen died in 1933.

Arctic polar bear. This giant creature has no natural enemies, except man. It has been hunted from boats and planes. In some years, nearly 10 per cent of the bear's numbers have been killed. Today the polar bear is protected by law.

The Caribbean monk seal *(Monachus tropicalis)* and the Mediterranean monk seal *(Monachus monachus)* are also endangered species. The former has not been seen alive since 1962 and is probably extinct. Fewer than 500 of the Mediterranean species may remain.

Rare species. Rare species are threatened by the same problems as endangered species. That is, their numbers are few or they live in such small areas or in such unusual environments that they could quickly disappear. The difference between the two categories is one of degree.

The Hawaiian monk seal *(Monachus schauinslandi)* is an example of a rare species. It is found only on six small islands extending norhwestward from the Hawaiian Islands. There are probably no more than 1,500 of these seals. They were killed for their fat by sealers in the late 1800s and almost became extinct. They have been protected since 1909 and have slowly increased in number to their present level.

Unfortunately, even stopping the killing may not be enough to save these seals. If they are disturbed on the beaches where they give birth, the mothers rush away into the water. Many of the pups left behind die. With all the Hawaiian monk seals located on just these few islands, it is easy to see how some local catastrophe, such as an oil slick, could wipe them all out. There are a few in captivity, but they have never bred.

Depleted species. Species classified as depleted still occur in sufficient numbers to survive. However, their numbers are greatly reduced from those of the recent past, and they are continuing to decrease. It is the continued decrease that is the main cause for concern. Animals in this category can quickly change to a rare or endangered status.

The addax *(Addax nasomaculatus)* of northern Africa is a member of the antelope family. It originally occurred in deserts from Egypt to Mauritania. This animal has been so heavily hunted that fewer than 5,000 survive all across their former range. They have been gone from Egypt since 1900, and they have also been wiped out in Tunisia. It is doubtful whether any exist in

The Bengal tiger. This animal has been hunted for centuries—first by Indian royalty, now by villagers who want to protect their families and livestock from the tiger. Less than 3,000 live in the wild

Libya, the Spanish Sahara, Algeria, or Sudan. Their last strongholds seem to be in Mauritania and Mali, where they are still hunted by nomadic natives, who dry the meat for food. The number of addax antelope continues to decline. If the population continues to decrease much longer, the species will become extinct. However, if the hunting were stopped today, there would still be enough animals and a habitat extensive enough for the species to survive.

Indeterminate species. A fourth category of threatened species is called indeterminate. It consists of species that seem to be in danger. However, there is not enough information on them to make a reliable estimate of their true status.

Species in this category include the three-banded armadillo *(Tolypeutes tricinctus)* of northeastern Brazil, which is hunted for its flesh; the short-eared rabbit *(Nesolagus netscheri)* of Sumatra, which is disappearing as the forests are cleared

Joe Bilbao/PR

Southern bald eagle, national symbol of the United States. Only several thousand of these birds exist today. They are protected by law

for agriculture; the Mexican prairie dog *(Cynomys mexicanus)*, which is killed for food and whose habitat is being taken over for agriculture; and the Central American tapir *(Tapirus bairdii)*, whose habitat is also being destroyed by man.

Usually, when more is learned of an indeterminate species, its status changes to a more threatened one. The status of the Amazon manatee *(Trichecus inunguis)*, a freshwater sea cow, was considered indeterminate in 1966. Within two years its condition was determined and changed to endangered. Hunted for its flesh, it is now among the most seriously threatened species. The snow leopard *(Leo uncia)* followed the same pattern from indeterminate in 1968 to endangered in 1970. The snow leopard is hunted for its thick, beautiful fur.

The "Red Data Book." In 1966 the IUCN produced the *Red Data Book*, a loose-leaf volume of information on the status of many kinds of animals. As the status of the animals changes, new pages are sent to subscribers. Pink pages indicat critically endangered species. Green pag are issued for those species that were f merly endangered but that have now r covered to a point where they are no long threatened. There are pitifully few gr pages in the book, and the number of p pages continues to increase.

WHY SPECIES BECOME ENDANGERED

Species become endangered for va ous reasons, but today almost all of th can be related directly or indirectly to ma They include hunting, loss of habitat food supply, low population levels, poisoning of the environment.

Hunting. Hunting threatens a vari of animals. Some animals are sought trophies; others are hunted for comme purposes.

The polar bear *(Ursus maritimus)* the Arctic is sought by hunters as a tro As long as the bears were chased by h ers on foot, they had a reasonable chanc escape. However, their numbers began decline when hunters started using planes and helicopters to find them chase them. When the bears become hausted, the plane lands, and the hunter his trophy.

Trophy hunters are also partially sponsible for the threatened position of tiger *(Leo tigris)*. These big cats are al killed by villagers trying to protect thei livestock. As the human population southern Asia increases, the amount of wi land where the tiger can safely live will di minish, and this cat may disappear. The t gers that lived on the islands of Bali, Suma tra, and Java are already virtually extinct. and few of the Siberian, Chinese, or Caspian races remain.

Other species are threatened because they are hunted commercially. The spotted cats, especially the cheetah *(Acinonyx jubatus)*, leopard *(Leo pardus)*, jaguar *(Leo onca)*, ocelot *(Felis pardalis)*, and margay *(Felis wiedii)*, are all threatened to varying degrees. They are hunted for their fur and for sport, and to protect livestock. Hunting for sport is most easily controlled. Commercial and protective hunting are more

Commercial hunting has endangered many types of whales. Here a whale is being flensed, or stripped of its skin. Many nations are now involved in attempts to limit the take of most species of whales.

difficult to regulate and are the most dangerous to the species.

Cheetahs are probably extinct in India, and their range is much reduced in the Middle East and in Africa. The number of leopards has also been greatly reduced. Until 1970, when new legislation went into effect, many of these cats were killed each year for their fur. Thus in certain areas their populations have been reduced to seriously low levels. The South American wild cats—jaguars, ocelots, and margays—have also been killed for their fur. They have already disappeared from many areas where they once lived, but sufficient numbers probably survive for the safety of the species if the commercial hunting is stopped.

Commercial hunting is directly responsible for the endangered status of many kinds of whales. These animals are killed mainly for the oil extracted from their blubber, for human and animal food, and for fertilizer. The giant blue whale *(Balaenoptera musculus)* has become endangered in recent years because the number killed annually by hunters was greater than the number born. In the mid-1950s there were 30,000 to 40,000 of these huge mammals, some of which reached more than 30 meters in length. In the following years these whales were widely hunted, and each year, more were killed than were born. In 1965, there was a moratorium placed on taking blue whales. Today, there are an estimated 12,500 blue whales.

The Tasmanian wolf and the American red wolf *(Canis rufus)* both prey on livestock. For this reason they have both been ruthlessly killed by farmers and professional hunters, and their populations have dropped to the endangered level.

Loss of habitat and food supply. The indirect threats to animals and plants are probably more dangerous, more widespread, and less known or evident than direct threats, such as hunting. Most of the threatened species are not hunted or directly killed by man. Instead, they are being endangered by the loss of their habitat or food supply.

An example of such a species is the ivory-billed woodpecker *(Campephilus principalis)*, which once inhabited the great forests along the Mississippi River and the swamps of Florida. This bird disappeared as the tall trees were cut down. Although there have been no confirmed sightings of ivory-billed woodpeckers for 30 years, there may still be a few of them remaining in Louisiana. Whether these few birds, if they still exist at all, will be enough to preserve the species from extinction is questionable at present.

The American black-footed ferret *(Mustela nigripes)*, a member of the weasel family, was closely associated with the prairie dog *(Cynomys ludovicianus)*, a grassland rodent. The ferrets not only fed almost exclusively on the prairie dogs, they also lived in their burrows. Because the prairie dogs ate grass desired for livestock, they were exterminated from most of their range. As these little animals disappeared, so did the ferrets, who had relied on them for food and shelter. There may be fewer than 100 black-footed ferrets remaining in the United States, and their situation is not hopeful.

The loss of their home threatens many forest species, especially on the island of Madagascar. The lemurs, which are found only on this island, may soom become extinct because they have no forests left in which to live. Along with the lemurs, the aye-aye *(Daubentonia madagascariensis)* will also disappear.

The aye-ayes, of which there are perhaps fifty left, are among the most gravely endangered species. These specialized primates feed on wood-boring insects, which they detect with their excellent hearing. They gnaw open the wood with strong front teeth and remove the grubs or adult insects with a highly specialized, long, skinny middle finger. Without the forests and the insects the aye-aye cannot survive.

Other animals endangered by the destruction of forests include the orangutan *(Pongo pygmaeus)* and the mountain gorilla *(Gorilla gorilla beringei)*.

Population levels. Some species are regarded as threatened with extinction because their numbers, while relatively stable are so small that they may never be able to increase to a truly safe level. Any small population, especially if all the animals are found within a single region, can easily be wiped out by one catastrophic occurrence such as a flood or a fire.

An example of such a species is the American whooping crane *(Grus ameri- cana)*, whose numbers were down to only 30 birds in 1933. Despite the fact that the were protected from hunters and we heavily guarded, there were still only birds in 1963. Although the whoopin cranes have numbered 50 or more since then, there may be too few to assure survival of the species.

Poisoning of the environment. Anot threat to wildlife has developed and creased in recent years—the poisoning the environment. As the human popula has grown, it has become more and m difficult to produce enough food to feed people on earth. Increasing amounts wild land have been cleared for agricu thus depriving animals of their homes. And new agricultural techniques have required increased use of poisons.

Herbicides to kill weeds and insecticides to kill insects have been dumped on the land in huge quantities to increase crop production and improve human health. It cannot be denied that such chemicals have been very helpful in terms of crop productivity and the eradication of disease. However, many of these poisons do not undergo a rapid chemical breakdown, and they remain in or on the soil until they are washed into streams and rivers. From the rivers the poisons are carried to the oceans.

In the water the chemicals are eaten or absorbed in tiny quantities by microscopic organisms. As these tiny animals and plants are eaten by larger and larger animals, the poisons accumulate in the bodies of the animals in increasingly high concentrations. Thus, the largest animals—those at the end of a so-called *food chain*—take in the highest concentrations of poisons.

For example, contaminated algae may be eaten by a small crustacean, which in turn is eaten by a small fish. The small fish

may then be eaten by a larger fish, and the larger fish eaten by a polar bear. This progression makes up a food chain. The polar bear at the end of the chain gets the most poison.

Some species are now threatened with extinction because of the effects of these poisons. This is particularly true of birds, many of which are laying imperfect eggs because of the accumulation of insecticides in their bodies. Some insecticides cause the production of very thin eggshells, so that the eggs break when the parents brood them. Eventually, the birds stop laying eggs altogether. Affected species include the American bald eagle *(Haliaeetus leucocephalus leucocephalus)*, the peregrine falcon *(Falco peregrinus anatum)*, the brown pelican *(Pelecanus occidentalis carolinensis)*, and a number of other birds.

Mercury is used to kill slime mold and fungus in agriculture and in industries. This poisonous heavy metal has also found its way into the sea, where it accumulates in living organisms. In some areas certain fish have been rendered at least temporarily inedible by the high concentrations of mercury in their bodies.

Some of the sea mammals that feed heavily on fish are starting to show high concentrations of mercury and insecticides. California sea lions *(Zalophus californianus)*, and Alaskan fur seals *(Callorhinus ursinus)*, and even polar bears in the Arctic and penguins in the Antarctic have been affected. Although none of these chemicals has been used in either the Arctic or the Antarctic, the poisons are present in the cells of ocean plants and animals.

Chemicals called polychlorinated biphenyls, which are used in insulating fluids, paints, plastics, and rubbers, are also found in the sea. They may be responsible for the high numbers of deformed terns that are now hatching on an island at the mouth of Long Island Sound, between New York and Connecticut.

The chemical fertilizers that are used to increase crop production wash into rivers and lakes, where they over fertilize the plants that grow in the water—a process known as *eutrophication*. The water plants, especially the algae, increase to a point where they take up all the available oxygen in the water. As a result fish and other animals die from lack of oxygen.

The indiscriminate use of poisonous chemicals, which are heedlessly dumped on the earth, may now represent the greatest threat to plant and animal life, including man. The most serious part of this situation is that even if we stopped using all these poisons today, they will continue to wash out and pollute the environment for many years to come.

PROTECTIVE MEASURES

The protection of animals has been practiced for centuries. Private hunting preserves, in fact, were one of the first conservation methods. The nobles who owned the land undertook to protect and nurture certain animals so that there would be an assured supply of them for sport. There are a number of species, especially in the deer family, that owe their existence today to the protection of the very men who hunted them.

Since the 1600s local laws have been used to protect native species that were disappearing. The first protective laws in the New World were probably those passed by the Bermuda government in 1621 to protect a bird called the cahow *(Pteradroma cahow)*. It appeared that, despite the law, this bird had become extinct. However, in 1950, a few live specimens were discovered. They are now carefully protected. In 1694 Massachusetts set a closed season on white-tailed deer *(Odocoileus virginianus)* because too many had been shot.

Today the Survival Service of the International Union for the Conservation of Nature and Natural Resources is the main agency for calling attention to endangered species. At its headquarters in Morges, Switzerland, the Survival Service receives reports from naturalists throughout the world about the status of various species. When someone informs the agency of a threat to a species, the Survival Service contacts other scientists who have knowledge of the animals or of the area concerned to try to learn what the condition of

by law in other countries are also forbidden [illegible].

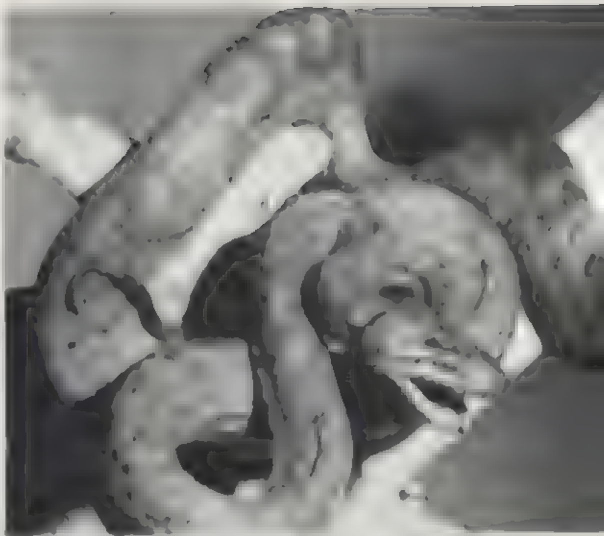
One of the problems of protection is that a species may be relatively abundant in one place but very rare in another. It may be protected in the country where it is rare and not in the other. Many animals are illegally killed in the country where they are protected and the skins are smuggled into the country where such killing is legal. It is extremely difficult, if not impossible, in many cases to tell just where the animal [illegible] by looking at the skin alone.

Many skins that came into the United States were listed as having come from places where the species was abundant and unprotected. However, they were in fact illegally killed in a protected country. For example, alligators were protected in the United States, but many were killed by poachers, smuggled to Europe, and were then imported back into the United States [illegible]. The same was true of leopard skins, which were identified as coming from [illegible], where killing was legal, when they actually came from Kenya, where it was against the law to kill them.

In 1970 New York State passed endangered species legislation known as the Mason Act. Designed to stop the type of circumvention of law described above, the Mason Act banned commerce in any [illegible] alligators, crocodiles, or any of [illegible] – whether they were endangered or not. The law also banned all trade in leopards, cheetahs, polar bears, red [illegible], tigers, snow leopards, and various other species no matter where they came from.

Since New York is the center of the fur and fashion industries, the Mason Act has proved to be one of the most potent pieces of legislation ever passed to protect endangered species. Other states have followed New York with similar laws, and in 1972 some of the most important points in the Mason Act were incorporated into a modification of the U.S. Endangered Species Preservation Act.

In 1973 the U.S. Endangered Species Act was extended to include insects. And in 1975 forty-one species of butterflies were



The Puerto Rican boa is a reptile native to Puerto Rico. Island species are often threatened with extinction because they are less able to migrate.

placed on the U.S. list of threatened and endangered species. These butterflies will be protected from interstate shipment, commercial sale, and mass collecting.

Only time will tell how successful these various protective laws will be. Some species, such as the California condor, the whooping crane, or the Guatemalan pied-billed grebe may not survive even though they are fully protected. Their numbers may be too few to provide the stock needed for population increase. Species such as the Alaskan fur seal, the sea otter, and the California gray whale were near extinction in the past. Happily, however, with careful protection and wise management the populations of these animals have been brought up to levels of relative safety.

The future of many species depends on the choices that man makes now. Commercial and trophy hunting are easily stopped by effective legislation and surveillance. Poisoning of the environment and destruction of habitats are less easily controlled. Mankind is capable of many things, but he cannot breathe life into a vanished species. What becomes extinct cannot be brought back.

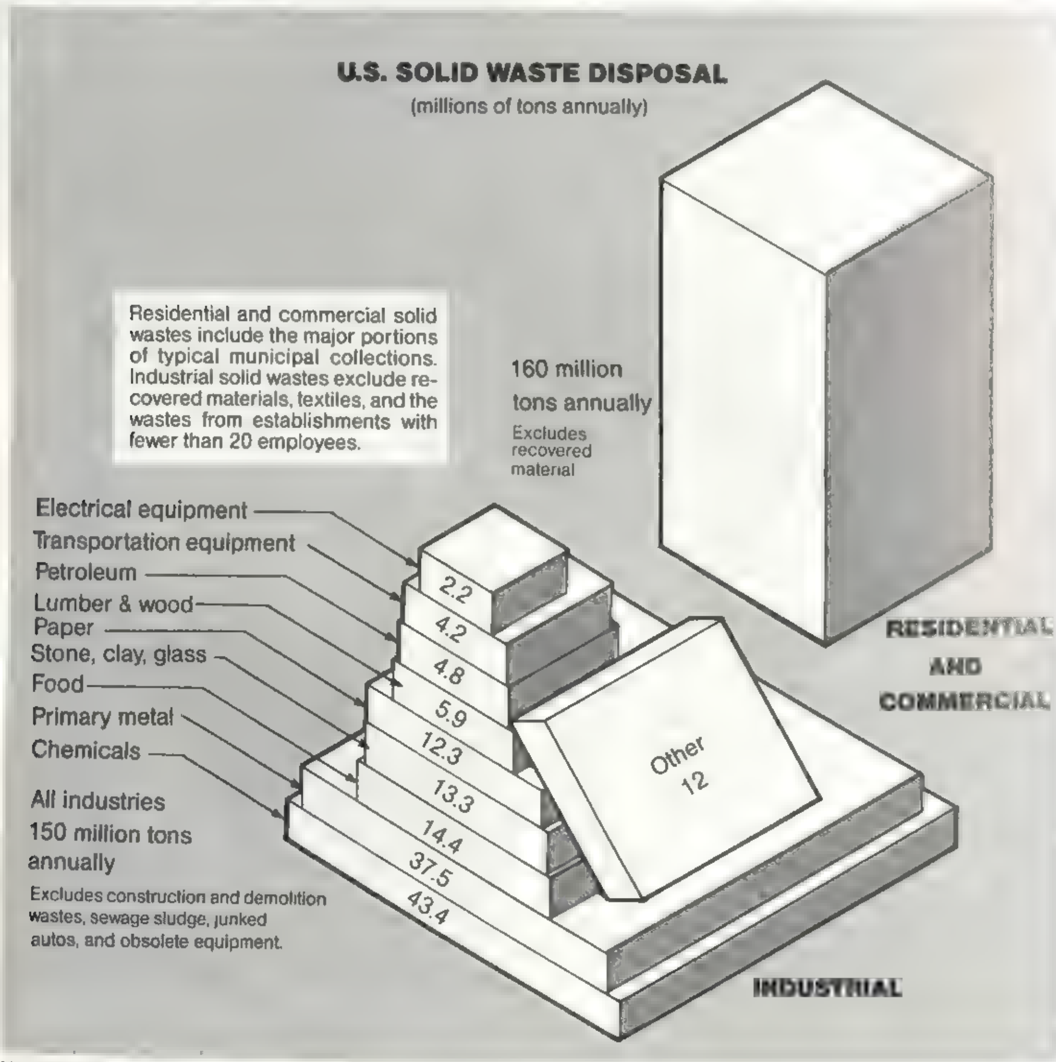
WASTE DISPOSAL

by Corliss G. Karasov

Every day we throw away countless forms of waste—from gum wrappers and banana peels to used car oil, old refrigerators, and an occasional battered car. Add to this the millions of tons of waste generated by agriculture, industries, mining, and oil and gas extraction, and you have about one million tons of solid waste generated every day in the United States (about four kilograms for every person). Another 315 billion liters of wastewater are poured into our sewers and septic tanks each day (1370 liters per person).

So much solid and liquid waste is gen erated that it would be impossible for natu ral processes to handle it all. Also, man forms of modern waste are persistent without special treatment they do not breal down in the environment for many years

What happens to this waste? Unfortu nately, it does not disappear with the flip o a garbage disposal switch or the flush of toilet. Mismanaged waste eventually show up as pollution in our lakes, streams, drin ing water, and air—even as an unsightly pil cluttering our view of the environment. I



dustrial and municipal wastes are the main source of groundwater contamination (half of our drinking water supply comes from groundwater sources). Waste management is a major nationwide problem today.

Waste disposal problems have attracted public attention during the past decade particularly because of concerns about hazardous wastes. More than 100 million tons of hazardous wastes are generated annually (excluding radioactive and nuclear wastes). These wastes must receive special treatment in order to avoid potential dangers to human health and the environment. Many new methods of treating nonhazardous and hazardous wastes have been developed. Unfortunately, though, we do not yet have totally satisfactory means of safely disposing of most wastes for long periods. Just as unfortunate is the fact that waste producers frequently do not utilize the safest disposal methods available, creating further disposal problems.

SOLID MUNICIPAL WASTES

The nomadic tribes of old were not bothered by the problem of waste collection. They simply cast aside their refuse. But as long as people have lived in communities, they have recognized the need for some sort of waste collection and disposal. This is particularly evident today—considering the large volume of waste generated. In 1982 alone, 160 million tons of solid municipal waste were collected in the United States.

COLLECTION

Modern communities can collect liquid wastes in sewers with ease and with relatively little expense per person. But there is no similar method for collecting solid wastes. Collectors still have to go to each home or place of business and gather the solid wastes, largely by hand, as they have done for centuries. This, or course, is expensive.

However, the work today is more sanitary than it was in the past. Special sanitation trucks have closed watertight bodies as well as special machinery that presses down the refuse into a small space.

DISPOSAL

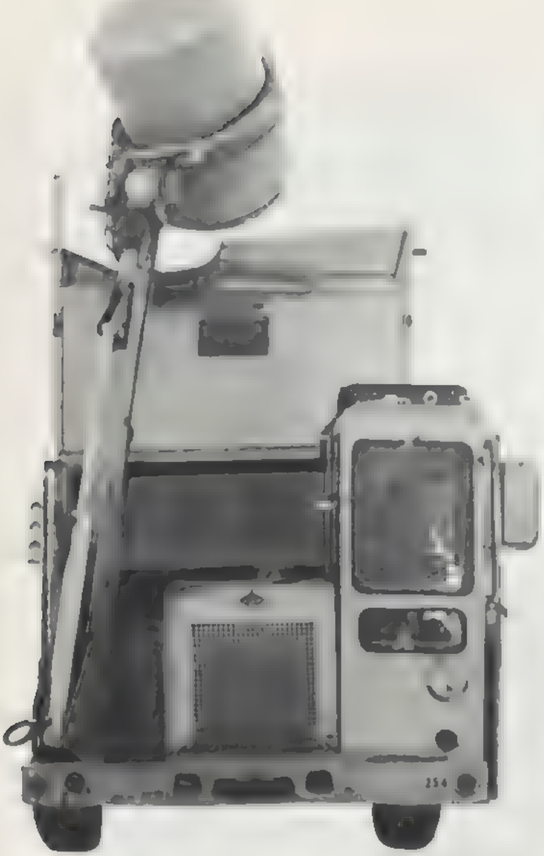
Once collected, a satisfactory method of disposing of solids is needed. The two most commonly used methods are incineration and sanitary landfills, though many other disposal techniques are available: open dump, hog feeding, grinding and discharge to sewers, milling, compacting, dumping and burial at sea, reduction composting, pyrolization (destruction with high heat), wet oxidation, and anaerobic digestion.

Incineration, or controlled burning of combustible waste, can be an effective waste reduction method for 70 percent of all solid municipal wastes. If an incinerator is operated properly, it can reduce bulk by 90 to 95 percent. Ash left over is generally disposed of in a landfill.

Environmental laws require specialized pollution control equipment such as scrubbers and electrostatic precipitators to remove fly ash (fine ash particles that would otherwise rise from chimneys and pollute the air).

Household waste being loaded into a truck that compacts it before hauling it to a dump or incinerator.

N.Y.C., EPA



City of Scottsdale Arizona

Above garbage truck equipped with special arm to lift trash containers Right an alley before the installation of closed trash containers and afterward when no litter spills from open cans

In the past the heat generated in incinerators went to waste. Today the heat is often channeled to heat boilers. There it produces steam, either for heating buildings or for generating electricity.

Sanitary Landfills are not open dumps. In this process, refuse is dumped at a preplanned site, compacted, and covered with a layer of earth. There are two basic approaches to making a sanitary landfill.

In the trench method, a tractor digs a trench with a bulldozer blade and trucks dump the refuse into it. Then the tractor compacts the refuse thoroughly and covers it with earth that was dug up earlier. The trench method is primarily used on level ground.

In contrast, the area method is generally used on rolling terrain where the existing slope of the land can be used a basin. In this method, trucks deposit ref over a selected area. Huge, heavy tractors with special compacting wheels press dow the refuse. Then the refuse is covered with earth hauled in from elsewhere. The tr tors make the fill so firm that it later settles only slightly.

Once a landfill has been compacted and covered, the land cannot be used to build homes or other buildings because of the danger of heavy objects sinking as the fill settles. However, many fills are used for golf courses and other light uses.

LIQUID MUNICIPAL WASTES

The disposal of sewage as we practice it today, with underground piping systems and treatment plants that purify the water, dates only from the 1800's. What sewers there were in antiquity—in India, Rome, and a few other places—served mainly to collect storm water (the runoff from rains) or to drain marshy areas.

U S EPA

Bill Shrout, EPA Documerica

Sanitary landfill is one way of disposing of refuse The upper photo shows "Mount Trashmore" in Virginia Beach, Virginia. It is a mound of solid wastes placed here as landfill. Each day a layer of waste is deposited and then covered with a layer of earth When completed the mound will be covered with topsoil and planted with vegetation. The golf course shown in the lower photo was established in a similar way

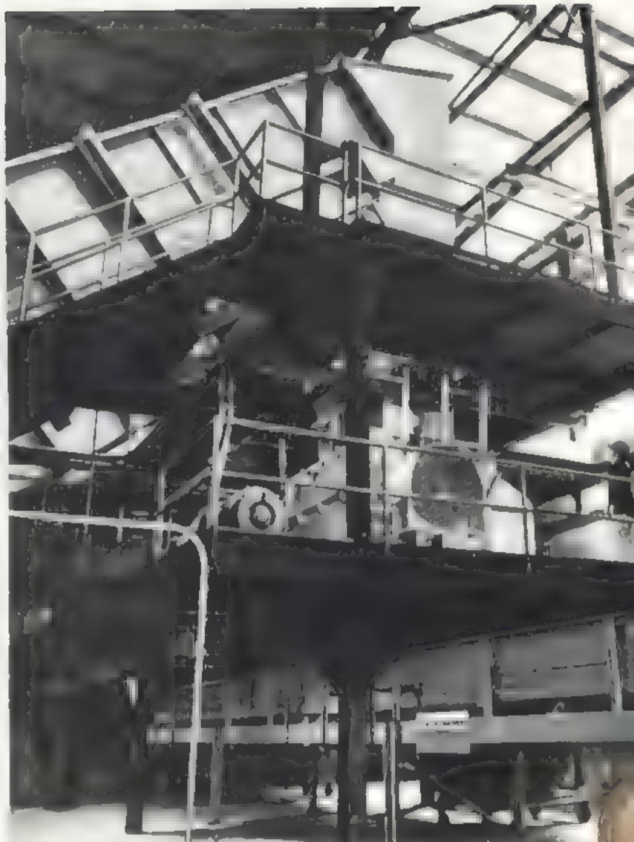


Photo Researchers, Inc

This solid-waste shredder carries waste to a hopper (top) from which it drops into a shredder mill. The waste is conveyed to a separator that removes metals and is then moved by truck to a landfill

In the Middle Ages, sewage flowed along open drains that ran through the streets. Households frequently disposed of garbage and human excrement simply by throwing them out a window into the street. Cities were filthy and epidemics were common.

Even today, open sewers are used in some underdeveloped areas of the world. In parts of Asia, people go to homes at night to collect human wastes and carry it away in carts. In parts of China and Japan, human waste is used as a fertilizer. Health authorities warn against this practice, however, since untreated human wastes can contain dangerous disease organisms.

Many towns have found the voluntary recycling of paper, glass, aluminum, waste oil and other materials reduces the demand on landfill sites and provides extra funds to the municipalities.

© Reed D. Brugger/Tl...

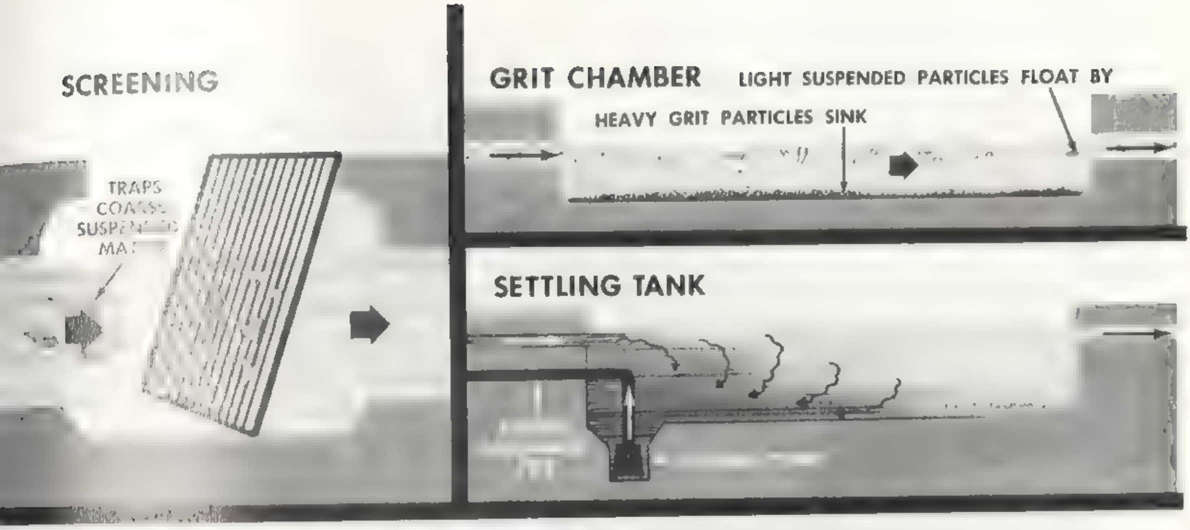
COLLECTION

Today elaborate sewer systems are used to carry most liquid sewage to waste treatment plants. This is the preferred method in most cases. When no sewage system is available, however, septic tanks and other subsurface systems are generally the next choice for homes and businesses.

Sewers are designed to carry sewage from residences, businesses, and industries through large conduits to sewage treatment plants where the sewage undergoes a series of treatment steps to remove polluting materials. Once treated, the wastewater is released to rivers and lakes to become part of our water resources. Sludge removed from the wastewater is treated and disposed of in landfills.

Most older sewer systems are designed to carry all forms of wastewater together, including both storm water and sanitary

The outfall of a city sewer pouring untreated liquid sewage into a river. The result is polluted water



Primary sewage treatment, involving the use of screens, grit chamber, and settling tank. Screening first removes coarse suspended matter, such as rags and sticks. Then, as sewage flows slowly through the grit chamber, heavy inorganic particles, such as sand, sink to the bottom; light organic particles move on. When the flow finally reaches the settling tank, the sewage is held for a time—say, three hours. Much of the suspended organic matter settles to the bottom of the tank as sludge. At one time, primary treatment was considered adequate, and the water was discharged into a stream or lake. Today, second- and third-stage treatments are often applied to sewage.


U.S., EPA

Solid waste compacted into bales, each one weighing almost 1,500 kilograms. This compacted waste is then often used for sanitary landfill.

sewage. A disadvantage of this "combined" sewer system is that most treatment plants are not designed to receive the large volume of sewage that comes through after rainstorms. Rather than damage the treatment plant with the excess waste after a storm, wastewater is often allowed to bypass the treatment plant and enter our waterways untreated.

Newer sewer systems often carry "blackwater" (toilet water) and "greywater" (any other water) separately. In the event of a rainstorm, greywater can be released if necessary while the more concentrated blackwater is treated. A second advantage of separated sewer systems is that greywater can in some cases be released after fewer treatment steps.

DISPOSAL

At the sewage treatment plant, sewage is put through a series of treatment steps to remove any biological and chemical contaminants that can harm human health or ecological systems; to remove final traces of suspended solids; to remove undesirable growths of algae; to remove taste, color, and odor; and to reduce nutrient content. Then the treated sewage is released to rivers and lakes to become part of our water

resources. The quality of the water released depends on the condition of the incoming water and the treatment processes used.

The three standard treatment stages are primary, secondary, and tertiary treatment. Primary treatment is almost always used. Although secondary treatment is recommended for most sewage, most treatment plants are not set up for secondary treatment. Tertiary treatment, a relatively expensive cleansing step, is used even less frequently, usually only when water of drinking quality is wanted.

Primary treatment is used to remove large floating or suspended particles, heavier particles such as sand or gravel (called grit), and any excessive amounts of grease or oil from the sewage. A series of screens, grit chambers, and sedimentation tanks is used for this step.

If no further treatment is performed, the wastewater is disinfected by the addition of chlorine and discharged into a stream or a body of water. If further treatment is needed, the wastewater goes to secondary treatment.

Secondary treatment is the use of aerobic microorganisms (bacteria that thrive in the air) to break down organic matter left in the sewage. The process—called biological oxidation—involves the use of trickling filters, activated sludge, and stabilization ponds. Unless tertiary treatment is used, the wastewater is disinfected with chlorine and discharged.

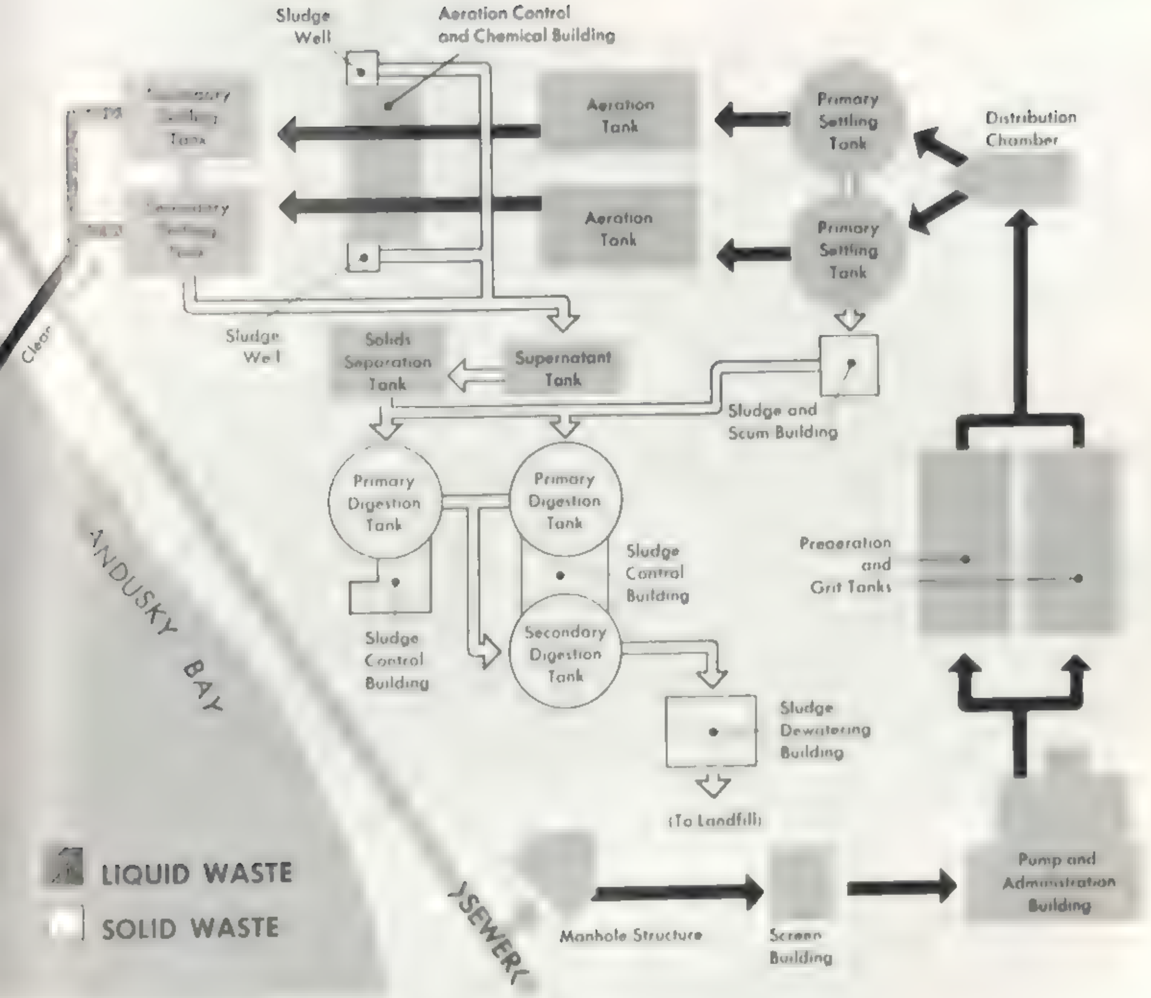
Sludge left over from the primary and secondary treatment processes is sent to a sludge digester for further processing. The sludge digester uses aerobic bacteria to break down volatile matter in the sludge over the course of two to three weeks. Methane, a by-product of this step, can be used as a fuel source. The remaining sludge can be used as fertilizer or a soil conditioner, incinerated, or deposited in a landfill.

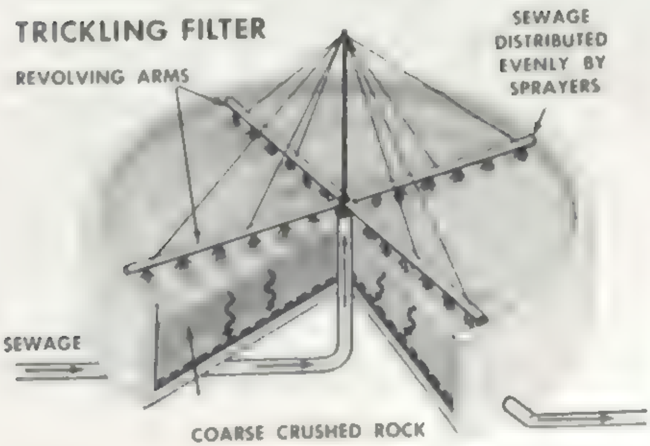
Tertiary treatment, also called advanced wastewater treatment, is used to get drinking-quality water. At this stage, chemical treatments are used to remove undesirable constituents that remain after secondary treatment. These include nitrates, which can cause public health problems and nitrogen and phosphorus, which encourage the growth of algae. The specific treatment methods used in tertiary treatment depend on the source of wastewater being treated. For example, carbon absorption, reverse osmosis, or distillation processes are used to remove organic materials. To eliminate heavy metals from wastewater, lime treatment or coagulation and sedimentation treatments are used.

The operation of a modern sewage treatment plant such as the Sandusky, Ohio, plant shown below, is simplified in the diagram at right. Sewage enters the plant at the manhole structure (lower left). Large debris is removed at the screen building. Sewage is pumped to grit tanks which remove cinders and similar matter. In the primary settling tanks, about 60% of the solid particles sink to the bottom as sludge. The sludge travels to digestion tanks where much of it decomposes and gases are drawn off. Then, excess liquid is extracted from the sludge, which now goes to landfill. The waste water in the primary settling tanks moves on to aeration tanks where pollutants are broken down. Secondary settling tanks capture more sludge and complete the chemical treatment of the waste water which is clean as it is released to the bay.

SEPTIC TANKS

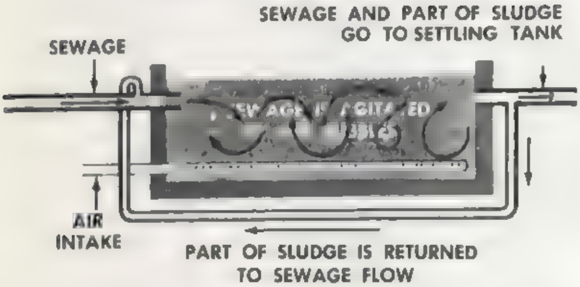
In areas without sewer pipes to carry sewage to treatment plants, septic tanks and other subsurface absorption systems are the most commonly used means of treating wastewater.





A trickling filter, which biologically purifies sewage of organic matter that often remains after primary treatment. This process is also known as aerobic purification, because aerobic, or air-breathing, bacteria destroy the organic wastes. Here sewage passes in a spray through openings in four arms, thus becoming mixed with air. The sewage then trickles slowly through a filter of coarsely crushed rock, where bacteria-carrying slimes break down the organic material into harmless substance.

ACTIVATED SLUDGE



Activated-sludge process of sewage purification. Sewage enters an aeration tank, where air is blown into the sewage through an intake. Bacteria-carrying slimes form as a result. They float in the sewage and pick up organic matter from it. The aerobic bacteria in the slimes then decompose the organic matter, producing sludge. Then the sewage and part of the sludge pass on to a settling tank. The rest of the sludge is returned to the sewage entering the aeration tank. The sludge fills the sewage with bacteria.

A *septic tank* is a watertight tank in which sewage is purified by anaerobic bacteria. Solid wastes settle to the bottom of the tank, where the anaerobic bacteria aid in their decomposition. Sludge left over is periodically collected from septic tanks and treated or disposed of in landfills.

The sewage effluent—wastewater—passes out of the tank through perforated pipes and into the surrounding soil. However, if the soil is too clayey or clogged with too much waste, the wastewater will not be able to leave the tank and be purified. Proper use of septic systems is important to ensure that the water is purified before it reaches nearby lakes, streams, rivers, or underlying groundwater.

INDUSTRIAL WASTE

Agriculture, mining, chemical and metal industries, and paper manufacture are responsible for a big chunk of the waste generated in the United States. Industrial mining and agricultural waste amount to more than 380 million metric tons of solid and liquid waste generated in the United States each year.

Industries generate most hazardous wastes. The two largest hazardous waste generators are the chemical industry (60 percent) and the primary metal industry (10 percent). Crude estimates of the hazardous waste disposed of in the United States each year run from 100 to 275 million metric tons.

Industries are now responsible for disposing of their own waste. This is often extremely costly. In response to rising costs for waste disposal, many companies have attempted to reduce the waste generated and recycle and reuse waste materials. Many industries have successfully reduced both nonhazardous and hazardous wastes. Even with these efforts, though, the volume of industrial waste generated annually in the United States continues to rise.

SOLID INDUSTRIAL WASTES

Most nonhazardous industrial waste is disposed of in sanitary landfills or incinerated as is done with municipal wastes (see the section on Hazardous Wastes for solid industrial hazardous wastes).

LIQUID INDUSTRIAL WASTES

There is no single best method for disposing of all industrial wastewater. The types of wastewater generated vary from industry to industry, and disposal methods depend on the specific forms of waste generated by each industry. Many nonhazardous wastes can be discharged directly into municipal sewer systems. Often, though, industries are required to pretreat their liquid sewage before discarding it—particularly if the wastes are corrosive and can damage sewer systems. In such cases, industries may be required to use primary, secondary, and tertiary treatment before releasing the wastewater. To accomplish this, many industries maintain their own sewage treatment facilities.

Treatment of industrial wastes is often less complex than treatment of municipal wastes because industrial wastes tend to be more homogeneous. It is generally easier to choose the appropriate treatment methods when you know precisely what is in the waste. Also, fewer treatment steps may be

© James H. Karales/Peter Arnold, Inc.

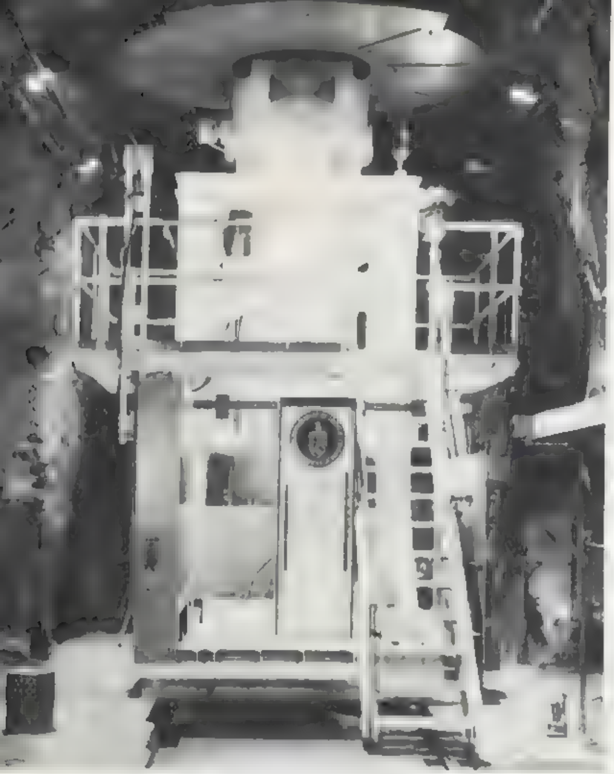
Homes in the Love Canal area of Niagara Falls, N.Y. being boarded up. Hazards from toxic wastes dumped there some 25 years earlier forced the removal of 400 families.

needed if the number of constituents in the waste is small. For example, metal industries often use chemical treatment processes on wastewater to reduce such chemicals as cyanide. The same procedures would not be necessary on organic wastes generated by food processors or the dairy industry.

HAZARDOUS WASTES

If the number of people interested in how waste is disposed of has increased, it is probably because of well-publicized tragedies associated with hazardous waste dumps such as Love Canal in Niagara Falls, New York. Damage to human health and the environment in these illegal or poorly managed dumps has underscored the importance of finding and using safe and lasting methods for disposing of hazardous materials.

Problems of dealing with hazardous materials are complicated by the large number of such materials involved. Almost 35,000 chemicals are classified as either potentially or definitely hazardous to human health. Some of these chemicals are toxic; the most commonly known can, in certain concentrations, cause birth defects, cancer, irreversible health problems, and death. Other types of hazardous wastes are corrosives, such as acids; flammables; explosives; irritants that can cause incapacitating short-term discomfort; and strong sensitizers that can trigger chronic allergic response reactions. Coming up with the



Atomic Industrial Forum, Inc

At a disposal test site in Nevada, a rail-mounted transfer vehicle is used to place canisters of spent nuclear fuel in underground storage holes.

safest and most effective disposal method for hazardous substances is often difficult.

Today standards for the transportation, storage, treatment, and disposal of hazardous wastes in the United States is established by the Resource Conservation and Recovery Act (RCRA). One goal of the RCRA is to force all hazardous waste generators to implement acceptable disposal programs.

HAZARDOUS WASTE DISPOSAL

In the past, when regulations were more lax, landfilling was the primary disposal method for hazardous wastes. A typical landfill consisted of a hole dug in clay and filled with unconsolidated sludge and drums of chemicals. The hole was then covered with soil and sealed with clay to keep out moisture. The use of long-lasting containers capable of storing highly corrosive materials was not yet mandated.

Such a disposal system is riddled with serious problems. For example, a layer of clay is inadequate to prevent water from seeping into the dump, mixing with the wastes, and sinking down into underlying water tables or nearby waterways. Steel drums containing corrosives cannot prevent their contents from eating through the steel and leaking out. As a result of lax landfilling methods and other poor disposal, groundwater contamination is now reported in every state.

Today about 80 percent of all hazardous wastes are disposed of on land—in landfills; in surface impoundments such as ponds, lagoons, and dug basins; and by underground injections. Another 15 percent of all hazardous wastes are destroyed through incineration.

An effective landfill for hazardous wastes is designed to reduce or eliminate the amount of hazardous materials seeping from the fill. Advanced landfill designs include at least special bottom liners, separation of hazardous materials, a collection and recovery system for the liquids that leach out, and a final top cover. The landfill cover is also shaped to divert surface water runoff to avoid water sinking in and mixing with the wastes. An effective landfill also includes a groundwater monitoring system.

Surface impoundments—depressions in the ground—include lagoons, treatment basins, pits, and ponds. They can be natural or artificial, lined or unlined. Surface impoundments are frequently used for wastewater treatment or temporary storage. Many impoundments have major leakage problems that make them poor sites for permanent disposal.

Incineration, or destruction at high temperatures, is performed in several ways, including liquid injection, rotary kiln, cement kiln, boilers, multiple-hearth incinerators, and incineration at sea. Once the waste is incinerated, the ashes are disposed of in landfills. Incineration may be one of the most effective means for dealing with many highly toxic substances. However, it is also one of the more expensive systems.

In *deep-well injection,* wastes are pumped into porous sandstone and limestone formations 300 to 900 meters below the earth's surface.

selected readings

EARTH SCIENCES

GENERAL WORKS

Brunsden, Denys, and John C. Dorrnkamp, eds. *The Unquiet Landscape.* Bloomington: Indiana University Press, 1975, 171 pp.—Rivers, valleys, hills, their development, and the processes that change them; an introduction to geomorphology, for grades 7–12.

Foster, Robert J. *Physical Geology.* Columbus: Charles E. Merrill, 2d ed., 1975, 421 pp., illus.—Good textbook introduction for the beginning student of geology; good illustrations

Gilluly, James, et al. *Principles of Geology.* San Francisco: W. H. Freeman, 4th ed., 1975, 527 pp.—Revision of classic text to include plate tectonics; outlines major geological concepts.

Harrington, John W. *Dance of the Continents.* Boston: Houghton Mifflin, 1983, 254 pp., illus.—Adventures in geologic time, showing how science is done.

Northern Survival. New York: Scribners/Employment & Related Services Division (Canada), Dept. of Indian Affairs and Northern Development, 1980; 105 pp., illus.—A no-nonsense survival handbook for survival in northern Canada and Alaska

Our Magnificent Earth: A Rand McNally Atlas of Earth Resources. Chicago: Rand McNally, 1979; 280 pp., illus.—Handsome coverage of minerals, energy sources, forests, and the like

Strahler, Arthur N. *Physical Geography.* New York: John Wiley, 4th ed., 1975, 699 pp., illus.—A classic text on the physical nature of the earth, with profuse illustrations; can be enjoyed by the general reader

Wyllie, Peter J. *The Way the Earth Works: An Introduction to the New Global Geology and Its Revolutionary Development.* New York. John Wiley, 1976, 296 pp., illus.—Textbook on plate tectonics, with a good list of other sources; intended for nonscience college students but useful to the general reader as well

Young, Patrick. *Drifting Continents, Shifting Seas: An Introduction to Plate Tectonics.* New York: Franklin Watts, 1976, 90 pp., illus.—How the mysteries of the earth's crust have been explored and the pieces of the puzzle put together; for younger readers

EARTHQUAKES AND VOLCANOES

Bauer, Ernst. *Wonders of the Earth.* New York: Franklin Watts, 1973, 128 pp., illus.—Clear account of how volcanism and other activities within the earth change the earth's appearance

Brown, Billye Walker, and Walter R. Brown. *Historical Catastrophes: Earthquakes.* Reading, Mass.: Addison-Wesley, 1974; 191 pp., illus.—Presents current knowledge of earthquakes and their effects through study of nine major quakes; for grades 6–9.

Cazeau, Charles. *Earthquakes.* Chicago: Follett, 1975, 32 pp., illus.—Review of what is known about earthquakes and the science of seismology; for grades 6–9

Davis, Alan. *Inside the Earth.* New York: Grosset & Dunlap 1973; 48 pp., illus.—Good historical survey, section on collecting geological specimens

Energlyn, William D. E. *Through the Crust of the Earth.* New York: McGraw-Hill, 1973; 127 pp., illus.—Covers mines and caves, volcanism, earthquakes, plate tectonics, economic geology; for the general reader.

Palmer, Leonard, and KOIN-TV Newsroom. *Mt. St. Helens: The Volcano Explodes.* New York: Northwest Illustrated (dist. by Caroline House), 1980; 119 pp., illus.—Report on the process of volcanism as well as the specific event, in easy-to-understand language

MOUNTAINS AND DESERTS

Allison, Ira S., et al. *Geology: The Science of a Changing Earth.* New York: McGraw-Hill, 6th ed., 1974; illus.—Well-illustrated text on geological processes.

Cook, David, and Valerie Pitt. *A Closer Look at Deserts.* New York: Franklin Watts, 1975; 30 pp., illus.—Well-illustrated account of deserts, where they occur and why, their life forms

George, Uwe. *In the Deserts of This Earth.* New York: Harcourt Brace Jovanovich, 1977; 384 pp.—History of the earth's geology through study of its deserts

Wallace, David Rains. *Idle Weeds: The Life of a Sandstone Ridge.* New York: Scribners (Yolla Bolly Press, dist. by Sierra Club), 1980, 183 pp., illus.—Lively chronicle of the complex life of a ridge over a year's span

MINERALS

Chesterman, Charles W., with Kurt E. Lowe, *The Audubon Field Guide to North American Rocks and Minerals.* New York: Knopf, 1979; 850 pp., illus.—Excellent pocket-sized source of information

De Michele, Vincenzo. *Color Treasury of Crystals.* New York: Crown, 1974; illus.—Inexpensive source of basic information about minerals, with good pictures.

Dietrich, R. V., and Reed Wicander. *Minerals, Rocks, and Fossils.* New York: John Wiley, 1983; 212 pp., illus.—A readable guide to the discovery, identification, and display of minerals, rocks, and fossils

SOILS

Keen, Martin L. *The World Beneath Our Feet: The Story of Soil.* New York: Julian Messner, 1975; 96 pp., illus.—The story of soil formation from geological beginnings, and man's misuse of the soil; experiments; for grades 7–12.

CAVES

McClurg, David R. *The Amateur's Guide to Caves and Caving.* Harrisburg, Pa.: Stackpole Books, 1973; 191 pp., illus.—Endorsed by the National Speleological Society.

THE ATMOSPHERE AND CLIMATE

Battan, Louis J. *Weather.* Englewood Cliffs, N.J.: Prentice-Hall, 1974; 136 pp., illus.—Atmosphere, air motions, storms, clouds, and earth climates explained for the high school student, good illustrations and book list

———. *Weather in Your Life.* San Francisco: W. H. Freeman, 1983; 230 pp., illus.—A nontechnical introduction to weather and its effects and how this information can be used to advantage.

Berger, Melvin. *The New Air Book.* New York: Crowell, 1974; 129 pp., illus.—The physics and chemistry of the atmosphere, with many suggested experiments; for grades 6–9.

Bernard, Harold W , Jr. *The Greenhouse Effect.* Cambridge, Mass.: Ballinger, 1980, 208 pp.—Description of possible future atmospheric problems caused by overuse of fossil fuels

Boucher, Keith. *Global Climate.* New York: Halsted Press, 1976; 335 pp., illus.—Modern text on climatology.

Brindze, Ruth *Hurricanes: Monster Storms from the Sea* New York: Atheneum, 1973; 106 pp., illus.—Current and historical information, including the use of satellites, and efforts to control hurricanes; for grades 6–9.

Roberts, Walter Orr, and Henry Lansford. *The Climate Mandate* San Francisco: W. H Freeman, 1979; 197 pp., illus.—Clear explanation of climatic variations and their effects, particularly on the world's food supply.

Schaefer, Vincent J., and John A. Day. *A Field Guide to the Atmosphere.* Boston: Houghton Mifflin, 1983, 359 pp., illus. —How to recognize, understand, and photograph atmospheric phenomena.

Simon, Seymour *Projects with Air.* New York: Franklin Watts, 1975; 63 pp., illus —How to carry out 27 kitchen projects showing how air behaves; for elementary students.

Wachter, Heinz. *Meteorology. Forecasting the Weather.* New York: Franklin Watts, 1973, 128 pp., illus.—A clear discussion of the elements that make up weather.

Young, Louise B. *Earth's Aura.* New York: Knopf, 1977; 305 pp., illus.—Well-written and far-reaching account of the earth's atmosphere and weather.

WATER AND ICE

Deming, H. G. *Water: The Fountain of Opportunity.* New York: Oxford University Press, 1975; 342 pp., illus.—Nonmathematical discussion of water in soils, water bodies and living things; role of water in earth cycles; its use and misuse by man; for senior high school or college students.

Fodor, R. V. *Angry Waters: Floods and Their Control.* New York: Dodd, Mead, 1980, 64 pp., illus.—Description of some major floods, their causes and prevention; for grades 4–6.

Imbrie, John, and Katherine Palmer Imbrie. *Ice Ages.* Short Hills, N.J.: Enslow, 1979; 224 pp., illus.—Clear and bright history of the evolution of theories about the glacial epochs.

Matthews, William H., III. *The Story of Glaciers and the Ice Age.* New York: Harvey House, 1974; 142 pp., illus.—Well-illustrated discussion of how glaciers are formed and how they move; question-and-answer format; for grades 6–9.

Schultz, Gwen. *Icebergs and Their Voyages.* New York: Morrow, 1975; 95 pp., illus.—How icebergs are formed and what happens to them, how they are dealt with, and how they may be used in the future; for the general reader.

Shannon, Terry, and Charles Payzant. *Antarctic Challenge: Probing the Mysteries of the White Continent.* Chicago: Children's Press, 1973, 80 pp.—Wide-ranging discussion of the history and exploration of Antarctica, with maps and many photos; for grades 6–9.

OCEANOGRAPHY

Barton, Robert. *Atlas of the Sea.* New York: John Day, 1974; illus.—The characteristics of the sea, its resources, man's activities there; 30 major maps, many diagrams

Cousteau, Jacques-Yves. *Jacques Cousteau: The Ocean World.* New York: Harry N. Abrams, 1979; 446 pp., illus.—Readable text from Cousteau's 1972–74 work, with hundreds of new illustrations

Schopf, Thomas J. M. *Paleoceanography.* Cambridge, Mass.: Harvard University Press, 1980; 342 pp.—Broad-ranging collection of information on this relatively new science

Waters, John F. *The Continental Shelves.* New York: Abelard-Schuman, 1975; 142 pp., illus.—The nature and importance of the continental shelves, how they are explored; scientifically accurate text for grades 6–9.

HISTORY

McPhee, John. *Basin and Range.* New York: Farrar, Straus & Giroux, 1981; 215 pp.—Graceful and clearly written history of the earth's crust and of the science of geology

Natural Wonders of the World. New York: Reader's Digest (dist. by Norton), 1980; 463 pp., illus.—Explains the processes that have shaped some 500 natural phenomena, from Niagara Falls to Mt Everest; a ready reference

Reed, H. H., and Janet Watson. *Introduction to Geology.* Vol. 2, *Earth History,* Part 1, *Early Stages of Earth History,* and Part 2, *Later Stages of Earth History.* New York: Halsted Press, 1975; 221 pp. and 371 pp.—Comprehensive outline of earth history for all continents.

ENERGY

Adler, Irving. *Petroleum: Gas, Oil, and Asphalt.* New York: John Day, 1975; 48 pp., illus.—An introduction to the subject for elementary readers.

Butterworth, William E. *Black Gold: The Story of Oil.* New York: Four Winds, 1975; 224 pp., illus.—History of the development of oil as a resource; for high school students.

Chaffin, Lillie. *Coal: Energy and Crisis*. New York: Harvey House, 1974; 47 pp., illus.—A review of the subject for grades 4–7.

Daniels, George. *Solar Homes and Sun Heating*. New York: Harper & Row, 1976; 184 pp., illus.—Introduction to the technology of solar energy.

Gabel, Medard. *Energy, Earth, and Everyone*. New York: Anchor/Doubleday, 1980, 264 pp., illus.—Presents the advantages of unconventional energy sources.

Halacy, D. S., Jr. *The Energy Trap*. New York: Four Winds, 1975; 143 pp., illus.—Covers all energy resources and present needs, for junior high and senior high school readers.

Healy, Timothy J. *Energy, Electric Power, and Man*. San Francisco: Boyd & Fraser, 1974; 355 pp., illus.—The story of man's misuse of electric energy

Hoyle, Fred, and Geoffrey Hoyle. *Commonsense in Nuclear Energy*. San Francisco: W. H. Freeman, 1980, 88 pp.—Reasoned advocacy for the use of nuclear energy.

Hunt, V. Daniel. *Energy Dictionary*. New York: Van Nostrand Reinhold, 1979, 518 pp., illus.—More than 4,000 entries covering all types of energy.

Knight, David C. *Harnessing the Sun: The Story of Solar Energy* New York: Morrow, 1976; 128 pp., illus.—Introduction to the technology of solar energy.

Kovarik, Tom, Charles Pipher, and John Hunt. *Wind Energy*. Northbrook, Ill.: Domus Books, 1979; 150 pp., illus.—History and operational details of wind energy in easy-to-read style.

McPhillips, Martin, ed. *The Solar Energy Almanac*. New York: Facts on File, 1983, 240 pp., illus.—An introduction to the use of solar energy, with emphasis on passive solar heating for homes

Michelson, David Reuben. *Atomic Energy for Human Needs* New York: Julian Messner, 1973; 189 pp., illus.—What can be accomplished by using nuclear technology, and its potential for the future, including the use of isotopes in several fields, for grades 7–12.

Pringle, Laurence. *Energy: Power for People*. New York: Macmillan, 1975; 147 pp., illus.—Points out our waste of fossil fuels; reviews energy sources, their potentials and problems; for grades 7–12.

Ridpath, Ian, ed., *Man and Materials: Gas*. Reading, Mass.: Addison-Wesley, 1975; 31 pp., illus.—The story of natural gas, for younger readers.

Schora, Frank J., et al. *Fuel Gases from Coal*. New York: Mss Information Corp., 1975—Text on the potentials of coal gasification as a source of high-methane gas.

Sherman, Steve. *Home Heating with Coal: Energy for the Eighties*. Harrisburg, Pa.: Stackpole Books, 1980; 192 pp., illus.—Succinctly covers the basics of coal stoves, their installation and use

Stoker, H. Stephen, et al. *Energy: From Source to Use*. Glenview, Ill.: Scott, Foresman, 1975; 337 pp., illus.—The energy story in its full scope, with major emphasis on petroleum, natural gas, coal, and nuclear energy; for senior high school students.

ENVIRONMENTAL SCIENCE

Boyle, Robert H., and R. Alexander Boyle. *Acid Rain*. New York: Schocken Books, 1983; 146 pp.—The scope and history of the problem, with arguments and proposed solutions.

Dubos, René Jules. *The Wooing of Earth*. New York: Scribners, 1980, 192 pp.—Thoughtful essay on humankind's obligations to nature.

Elliott, Sarah M. *Our Dirty Water*. New York: Julian Messner, 1973; 64 pp.—The problem of water pollution and what people can do about it, with simple experiments for testing water, for elementary and junior high school readers

Lauber, Patricia. *Too Much Garbage*. Champaign, Ill., Garrard, 1974; 64 pp.—The story of the problem of garbage and how it can be better handled, for the younger reader

Laycock, George. *The World's Endangered Wildlife*. New York: Grosset & Dunlap, 1973; 152 pp., illus.—Well written and informative, with a list of organizations and a bibliography.

McGraw-Hill Encyclopedia of Environmental Science. New York: McGraw-Hill, 2d ed., 1980; 858 pp.—A valuable reference tool.

Margolin, Malcolm. *The Earth Manual*. Boston: Houghton Mifflin, 1975; 190 pp., illus.—Ways in which people can inexpensively protect the environment of woodlots, small forests, parks, yards, and so forth; good reading lists.

Milne, Lorus J., and Margery Milne. *Ecology Out of Joint: New Environments and Why They Happen*. New York: Scribners, 1977; 304 pp.—Absorbing account of the ways people can disturb their fragile environment.

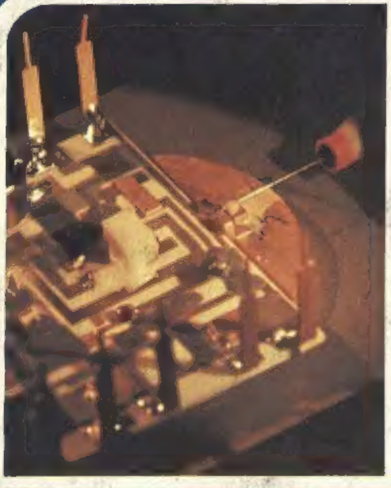
Murdoch, William W., ed. *Environment: Resources, Pollution and Society*. Sunderland, Mass.: Sinauer Associates, 2d ed., 1975; 488 pp.—An explanation of ecological systems and pollution problems; for the general reader

Pringle, Laurence P. *Recycling Resources*. New York: Macmillan, 1974; 119 pp., illus.—The disposal of solid wastes by incineration, landfill, and recycling; for grades 6–9

Tannenbaum, Beulah, and Myra Stillman. *Clean Air*. New York: McGraw-Hill, 1974; 64 pp.—Discussion of the kinds of air pollution.

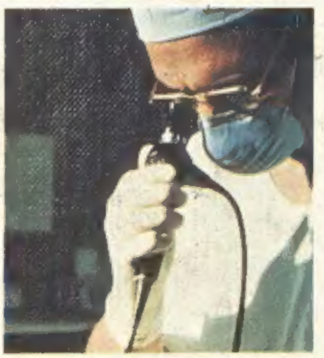
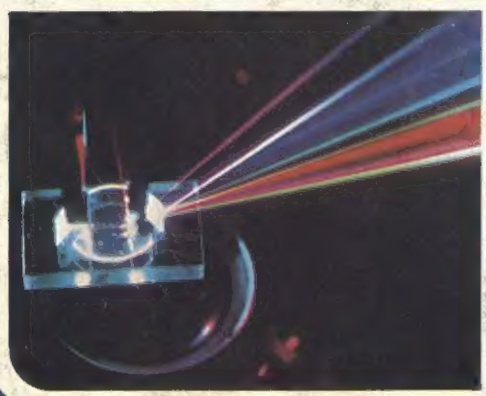
Walker, Charles A., et al. *Too Hot to Handle?* New Haven: Yale University Press, 1983; 209 pp., illus.—The history and technology of managing radioactive wastes, with discussions of the biological effects of radiation and attitudes toward nuclear energy

Watkins, T. H., and Charles S. Watson, Jr. *The Lands No One Knows: America and the Public Domain*. San Francisco: Sierra Club Books, 1975; 256 pp., illus.—Valuable reference work on U.S. public lands and their use and abuse, with a listing of primitive areas; the effect of exploiting energy sources; for the advanced reader








2

ASTRONOMY

SPACE SCIENCE

COMPUTERS

MATHEMATICS

EARTH SCIENCES

ENERGY

ENVIRONMENTAL SCIENCES

PHYSICAL SCIENCES

GENERAL BIOLOGY

PLANT LIFE

ANIMAL LIFE

MAMMALS

THE HUMAN SCIENCES

TECHNOLOGY